



WATER

KEY DRIVING FORCE

P.S. Datta



Vigyan Prasar

WATER: KEY DRIVING FORCE

Water is by far the most common substance on earth; and has always been an essential component for survival of human, animal or plant. Its supply is diminishing very rapidly. It is being generally abused, and is often ignored or taken for granted. For communicating the value of this commodity, it is essential to examine the occurrence of water, its conservation, its distribution and its use for irrigation, industrial developments and domestic purposes. This book is an attempt to provide information and understanding needed for wise management and the over all importance of Nation's water resources in developmental process besides creating awareness on water related issues and aspects.

About the author

Dr. P.S. Datta (b. 3rd June, 1950; Ph.D., IIT, Kanpur) is currently Project Director in Nuclear Research Laboratory, Indian Agricultural Research Institute, New Delhi. His major research interest has been in the field of applications of isotope techniques in hydrological investigations for water resources assessment and management and environmental impact assessment in river basins in the Indo-Gangetic Alluvial Plains; Sabarmati River Basin and Agroecosystems of semi arid and arid regions.

He has wide experience in various investigations on water resources assessment, environmental impact assessment, estimation of groundwater recharge, groundwater contamination characteristics; influent and effluent seepage; groundwater - surface water interactions etc. He has published over one hundred and ten research papers in various International and National journals of repute. He has authored one book, and three scientific reports on water related aspects. He has received many national and international recognitions/honors/ awards.

He has been the Member Secretary In-Charge of the High Level Technical Committee on Hydrology, Govt. of India, in the context of the International Hydrological Programme of UNESCO and Asjan Regional Coordinating Committee on Hydrology, UNESCO.

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Foreword

Earth is the only planet we know of with life on it. Animals, Plants and microorganisms maintain a delicate balance with a variety of life forms we call Biodiversity. Each species depends on other species for its existence. When we talk of life on earth, we also talk about the human species. If we need to understand and preserve our environment, we shall need to understand the interdependence of the species on each other and the importance of natural resources like air, water and soil for living beings.

Life has continued to evolve on this earth over millions of years adapting to changing environment. Only those species have survived that have adapted to the changing environment. This change could be due to natural causes like earthquakes, eruption of volcanoes, cyclones, and so on. It even could be due to climate change. However, quite often this change is brought about by the species higher up in the ladder of evolution that tries to control environment to suit its needs and for development. This is precisely what human species has done to our fragile planet.

We need energy for development; which we traditionally obtain by burning natural resources like

firewood, coal and petroleum. This is what we have been doing for centuries. Today there is consensus that human activities like burning of fossil fuels and consequent pumping of gases like carbon dioxide into atmosphere have been responsible for the earth getting hotter and hotter. Today, there are threats to our planet arising from climate change, degrading environment, the growing rate of extinction of species, declining availability of fresh water, rivers running dry before they can reach sea, loss of fertile land due to degradation, depleting energy sources, incidence of diseases, challenge of feeding an exponentially growing population, and so on. The human population is now so large that the amount of resources needed to sustain it exceeds what is available. Humanity's environmental demand is much more than the earth's biological capacity. This implies that we are living way beyond our means, consuming much more than what the earth can sustain.

To draw the attention of the world to these aspects and in an attempt to establish that environment is where we live; and development is what we all do in attempting to improve our lot, within that abode, the United Nations has declared the year 2008 as "The Year of the Planet Earth". It is hoped that with the cooperation of all we shall be able to save the biodiversity and the life on this planet. A host of activities and programmes are being organized all over the world for this purpose. One of the important aspects is to make people aware about the challenges we face and the possible solutions to save this planet from heading towards catastrophe. It is with such thoughts that Vigyan Prasar has initiated programmes with activities built around the theme "The Planet Earth". The activities comprise of development and production of a series of informative booklets, radio and television programmes, and CD-ROMs; and training of resource persons in the country in collaboration with other agencies and organizations.

It is expected that the present series of publications on the theme "The Planet Earth" would be welcomed by science communicators, science clubs, resource persons, and individuals; and inspire them initiate actions to save this fragile abode of ours.

Vinay B. Kamble
Director, Vigyan Prasar
New Delhi

Preface

Water is by far the most common substance on earth; and has always been an essential component for survival of human, animal or plant. Its supply is diminishing very rapidly. It is being generally abused, and is often ignored or taken for granted. For communicating the value of this commodity, it is essential to examine the occurrence of water, its conservation, its distribution and its use for irrigation, industrial developments and domestic purposes. The importance of water in the overall development process has been increasingly recognized during the last three decades. Harvesting, conservation and reuse of water has taken place to improve water use. The United Nations World Food Conference (1974) felt the necessity of instituting proper control and management of water for both horizontal and vertical expansion of agriculture. Both the UN Conference on Human Settlements (Vancouver, Canada, 1976) and the UN Water Conference (Mar del Plata, Argentina, 1977) emphasized the plight of rural people in developing countries with no access to safe drinking water. The decade 1981-90 was declared as the International Drinking Water and Sanitation Decade in order to emphasize the magnitude and gravity of the problem and to rectify the situation. The United Nations declared the year 2003 as the UN

International Year of Freshwater. Besides the increasing requirements of water in quantity, maintenance of water quality has become an increasing focus of international concern.

Many flexible approaches to agricultural policies and planning in India around 1960s to 1980s have resulted in an agricultural revolution with increase in food-grain output during 1980s. Commendable though these advances are, much remains to be done to use India's water resources optimally and efficiently on a sustainable basis. Effective water management requires a clear understanding of the linkages between various water sources in a hydrologic setting. During 1983-85, as Member Secretary In-Charge, High Level Technical Committee of Hydrology, Min. of Water Resources, Govt. of India and ARCCOH (UNESCO), in the context of the International Hydrological Programme, I had an opportunity to interact with international team of experts to review water plan with water management agencies. Since then, I felt that all the alternatives and their potential benefits and costs should be carefully evaluated based on sound knowledge on water and related aspects before any final decision could be taken.

This book has been written with aim to popularize science, provide information and understanding needed for wise management of the Nation's water resources, and bring awareness on water related issues and aspects. The Chapter-1 and Chapter-2 of this book outline general significance of water, its origin, occurrence, distribution, renewal, physical and chemical properties, and geo-hydrological attributes of water systems, etc. The Chapter-3 and Chapter-4 describes the international and national scenario. The Chapter-5 deals with the general experiences gained from water projects in different parts of the world and future scope. The Chapter-6 presents proposed activities in India. This book offers some information for how to move forward in a collaborative, cooperative way to develop appropriate policies for ensuring that water resources issues are successfully addressed.

This book would not have been possible without continuing interest of Dr. V.B. Kamble, Director, Vigyan Prasar; Dr. B.K. Tyagi, and Dr. S. Mohanty, Vigyan Prasar from the beginning. I express my appreciation to them. I especially thank my wife and son for their encouragement.

P.S. Datta

December, 2007
New Delhi



Introduction

Water is the most valuable resource on the earth and an integral part of the environment. Its availability is indispensable to the efficient functioning of the biosphere. Settlement of most of the great ancient civilizations has been generally associated with a reliable and clean supply of water with convenient sources. For example, the Egyptians centered their civilization on the Nile. Mesopotamia (the land between the Tigris and the Euphrates rivers) was the home of several important ancient empires. Chinese civilization was located principally in the Yellow and Yangzi river basins. Since the dawn of Indian civilization, the *Ramayana*, *Mahabharata*, the *Arthashastra* by Chanakya (3rd century BC), *Puranas*, the *Vrahat Samhita* (550 A.D), the *Meghmala* (900 AD), Panini's *Astadhyayi* and various other Vedic, Buddhist and Jain texts contain several references to the various processes of hydrological cycle and traditional water harvesting structures and water being revered as a life giving and sustaining force. The bible quotes, 'I am the Alpha and the Omega, the beginning and the end. To the thirsty I will give water without price' - Revelation 21:6. In Islam, the *Sharia* law in Koran literally translates to laws of sharing water. Water facilitated relatively rapid transportation

prior to about 1850 C.E. From the late 15th through the 18th centuries, Europeans explored all the major oceans.

Besides earth, there are evidences of water in a variety of places in the Universe including: the Moon, Mars, Jupiter's moons, comets, and in interstellar clouds. Yet, until today, it is not clear why there is more water on the Earth than on the other planets of the solar system. Except for fossil water, all water on the planet Earth circulates throughout the atmosphere, geosphere and hydrosphere. Amazingly, less than 1% of the earth's water is available for human consumption. Almost one-quarter of the world population lacks a safe supply of water and half the population lacks adequate sanitation. Over 90% of the world's developing countries, located in arid and semi-arid areas, are under higher water stress. Over 50% of the world's population is estimated to be residing in urban areas, and almost 50% of the mega-cities having populations over 10 million are heavily dependent on groundwater, and all are in the developing world. Nearly 40% of global food production is attributed to irrigated abstraction, and 70% of the world groundwater withdrawals are used for irrigation purposes.

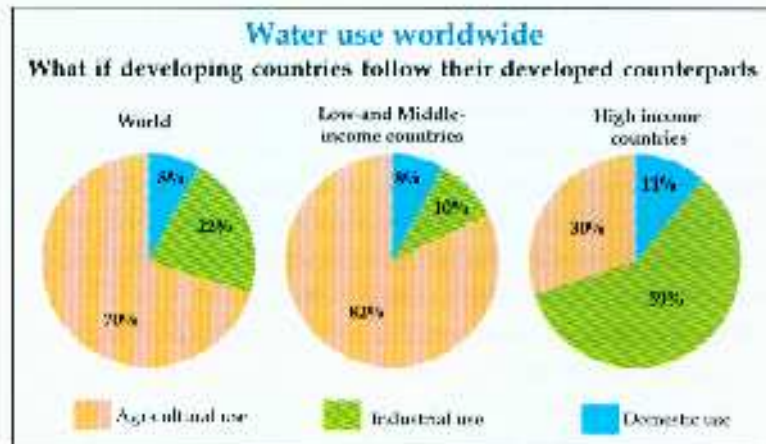
Safe and stable water supply is of vital importance to all socio-economic sectors development. Water has always been an important source of power, and remained an essential component in all kinds of manufacturing processes and one of the most important components of sustainable development. It is essential for natural habitat – for drinking, cleaning, agriculture, transportation, industry, recreation, animal husbandry, and providing electricity for domestic, industrial and commercial use. On the other hand, extreme events of more or less water may have an impact not only on the human society but also on the aquatic and terrestrial environments. Expanding human activities have greatly impacted the water cycle,

resulting in growing number of global water problems and life-threatening hazards. Misuses of water resources and poor water management practices have often resulted in depleted supplies. Most of the people take water for granted. For many, water becomes an important factor until one turns on a faucet or flushes a toilet and don't find flow of water. Conflicts over water have become more common among competing water users.

In recent times, due to increase in population, urbanization, industrialization and use of chemicals in agriculture, there is an ever-increasing threat to the quality of water resource base, resulting in decrease in fresh water availability. While this crisis is most pronounced in the developing countries, the developed world and economies in transition also experience major environmental problems and human health consequences. The problems also include water shortages due to imbalances between water demand and supply, and ecosystem deterioration, caused by improper land use. Erosion and sedimentation, floods induced by urbanization, the problem of fresh and salt water interaction both in the surface water and in the groundwater environment. The humid tropics and temperate zones, while normally associated with less dramatic hydrological phenomena than the arid zones, still remain in the focus of interest. Apart from these, water resources management problems exist in the fragile ecosystem of dry lands, wetlands, mountains, coastal zones and small islands, irrespective of their geographic/climatic location and land use such as urban, peri-urban and rural areas.

While the urban clusters look for low to moderate volumes of high-quality water, rural clusters look for large quantity of high-quality water, in inefficient field distribution and drainage systems. In many areas of India, due rise in water demand for irrigation and other purposes, inadequate

availability of surface water supply, groundwater will continue to be used intensively. Farmers adopt groundwater irrigation due to apparent reliability of storage offered by mechanized drilling and pumping, and flexibility of groundwater exploitation, but remain indifferent about quality unless the groundwater is saline. Increasing indiscriminate groundwater use has crossed the sustainable limits. In different parts,



environmental problems are evident, such as; lowering in groundwater levels, decline in productivity of wells, more seepage from canals, increasing trend of salinity and groundwater pollution, intermixing of contaminated water with fresh water, etc. The problem is also compounded by the complexities of the interactions among the physical, hydrological, meteorological and biological environment, management of the natural and the socioeconomic systems.

Increasing water use and pollution generation has crossed the sustainable limits in many parts. The story of each region or city may be different, but the main reasons for the water crisis are common, such as, increasing demand, zonal disparity in distribution of water supply, lack of ethical framework, inadequate knowledge and resources. Thus, the issue of water

management is multidimensional, related to reliable assessment of available water, its supply and scope for augmentation, distribution, reuse/recycling, its existing depletion, degradation, pollution and its protection from depletion and degradation. However, like surface water resource management, not much concerted efforts have been made for management of the hidden underground water resources. Water supply schemes, generating large amounts of wastewater, are normally designed and built, without the required matching drainage networks and wastewater treatment facilities. So far, water has been managed in a fragmented way. This fragmentation of approach also impedes coherent hydrological analyses at regional, continental and global scales. The incorporation of the social dimension underlines the need for improved, more efficient management of water resources and the more accurate knowledge of the hydrological cycle for better water resources assessment.

Since the latter half of the 20th century, rapid population growth and expanding human activities have given rise to a variety of serious water problems at the global, regional, and local levels. The expression, "the 21st century will be an age of water", embodies both the concern that water issues may cause international conflicts and the hope that these same issues will promote international cooperation. The growing concern for the water sector have been echoed repeatedly at several international forum beginning with the UN conference on the Human Environment, Stockholm in 1972 to the 3rd World Water Forum, Kyoto in 2003. United Nations declared the year 2003 as the International Year of Fresh Water. The UN General Assembly at its 58th session in December 2003 agreed to proclaim the years 2005 to 2015 as the International Decade for Action, "Water for Life", and beginning with World Water Day - March 22, 2005. To solve the aforesaid water problems, science-based research efforts must be promoted to clarify the

structural relationship between the water cycle and human activities, as well as establish a sound and sustainable relationship between them.

The increasing worldwide pressure on water resources under anthropogenic and environmental change requires an integrated multidisciplinary approach to address issues involving water resources assessment and management; taking a holistic view of the water resources, considering issues, such as, the quantity and quality of surface water and groundwater and their interdependence, freshwater and saltwater interface, urban growth and changing land use patterns, as well as risks and hazards of flood and drought; identifying the pertinent parameters, phenomena, processes and possible changes of the hydrological cycle, and evaluating the water requirement of different development alternatives; simultaneously addressing science and policy, based on reliable physical and socio-economic information. Enhancement in water availability and safe water supply will be guided by the policies, plans and technologies at our disposal, in addition to political, socio-economical, biological and other factors. Choices based on the best obtainable detailed scientific information, guided by ethical considerations, offer the best hope to protect water from depletion and pollution.



Basic Information

To have further insight on the origin of water in the universe and on the earth, let us discuss the origin of the elements hydrogen and oxygen that make up water molecules.

The Big Bang: 10 to 20 billion years ago, the Universe was in an extremely dense and hot (~10 billion °C !) state that exploded in what is called 'The Big Bang'. Eventually, the Universe expanded and cooled and huge collections of gas formed into billions of separate galaxies, and billions of stars formed within each. Many fundamental particles were formed in the beginning of this process, including the basic building blocks of all atoms: protons, neutrons, and electrons. The two lightest elements, hydrogen and helium, were also formed. Some heavier elements were created in the Big Bang, but only in very trace amounts, e.g., one lithium atom out of every 10 billion atoms. So how are the heavier elements, such as oxygen, formed?

Stellar Evolution: Stars, which contain mostly hydrogen, like Sun produce huge amounts of energy from *nuclear fusion*

in their hot cores. The pressure and temperature is so great in the core that hydrogen is fused together to form helium. 90 per cent of a star's lifetime is spent fusing hydrogen into helium. Once the hydrogen is used up, helium begins fusing and one of the by products of that process is oxygen. Depending on the mass of the star, all the heavy elements up to iron can be created in succeeding fusion reactions or *nucleosynthesis*. Due to the Big Bang created hydrogen and oxygen by nucleosynthesis in stars, and the fact that these elements are highly reactive chemically, water should therefore be fairly common in the Universe. However, only at certain temperatures and pressure, like those found on Earth, liquid water is expected to be found.

Detecting Water Beyond the Earth

Detecting water in the Universe up to now has been done almost entirely remotely. The composition of a planet's atmosphere and surface can be partially determined by analyzing the *spectrum* (a display of the intensity of light emitted at each wavelength) of light emitted or absorbed by the elements that compose it. A spectroscope splits the light into its components, like a prism, which shows the different colors (wavelengths) making up white light. Atoms of a given element can emit only light of specific wavelengths. Similarly, each type of molecules has a unique spectrum of light. Thus, if the spectrum of water is found to be present in the full spectrum of light that is observed from a given planet, the existence of water on that planet can be inferred. Water molecules have been detected in this manner in the atmospheres and the surfaces of some of the planets. In the last few years, planetary probes have detected tantalizing evidence that water may exist on other bodies in our solar system, though in fact no other planet or moon in our solar system has the amount of liquid water present on the earth. Specifically, the following is a partial list of evidence of the existence of water in the universe, detected spectroscopically and by other means:

- **Ice on the Moon:** Over the last couple of years, spacecraft orbiting the Moon has indicated the possibilities of a large amount of subsurface ice there.
- **Comets:** Comets (sometimes referred to as “dirty snowballs”) are chunks of dust and frozen gases including water that are in highly oblong orbits around the Sun. As they near the Sun, the sunlight melts some of the comet’s material, which results in a long tail.
- **Mars:** The spacecraft photographs of the Planet show long jagged structures that appear to be old rivers and canyons. Photographs taken recently show stacked boulders, probably deposited by raging floods. However, the atmospheric pressure on Mars is now 100 times less than that of earth, and therefore, water cannot exist as a liquid there anymore, and possibly much of the water exists as subsurface ice. There are polar ice caps (composed of frozen carbon dioxide, but small amounts of water-ice) that get larger during the Martian winter and smaller in the summer.
- **Europa:** The Galileo spacecraft orbiting Jupiter has photographed the surface of one of its moons, Europa, which appears cracked with many fissures, as if it is made of ice that freezes and then thaws repeatedly.
- **Interstellar Clouds:** The spectrum of water has been detected in interstellar gas/dust clouds. Water molecules in masers in interstellar clouds are stimulated by the energies of nearby stars.

The Origin of Water on Earth

The earth appears to be unique in the solar system in the sense that it contains an enormous amount of water, which has existed in more or less in its present state for billions of years. To know the reason for this, it is necessary to understand the processes that governed the formation of the earth and the evolution of the earth and its atmosphere. According to the

most recent theories of planet formation, two steps govern the process of planet formation: (i) Gravitational collapse takes place forming small asteroid like bodies, some as large as 1/500 of the mass of the earth. The planetesimals begin to collide and form the larger bodies of the planets; and (ii) when a meteor hits anything, some of it sticks and some is scattered back into space by the impact. The lower the density of the material, the more likely it is to escape. In the early stages, the earth collected heavier stuff more easily, leaving lighter stuff such as silicon and water still in orbit about the sun. However, it more effectively trapped the lighter material during the latter stages of planet formation.

The formation of the earth probably took a few hundred million years to be completed, as compared with the time of about 3.5 billion years since the earth has developed a solid crust. About the time the earth was formed, the sun became large enough that the fusion reactions in the sun ignited. This didn't happen smoothly, but likely in sputtering way for a while. Each flaring up of the sun sent streams of particles sweeping out. If the earth had an atmosphere at this time, it would have been blown off leaving the earth as a rock with neither air nor water on its surface. In fact, after the sun stabilized, the earth went through a process of releasing gases from its interior in a process called degassing. Over a relatively short time, around 100 million years, enough material had been released to form the oceans and to give the earth an atmosphere. There was no free oxygen in the atmosphere at this time, but it was a collection of gases, largely ammonia, methane and carbon dioxide, held to the earth by gravitational attraction. Fortunately, early in its history, the temperature of the earth dropped below 212 degrees Fahrenheit, and the water condensed into the ocean that exists today.

In fact, the mass of water present in the oceans now (about 10^{24} grams), is about the same as the mass of water that was

contained in the crust when the degassing process started only a few hundred million years ago. The rate at which water is being lost today can be estimated by calculating the rate at which water molecules in the atmosphere are dissociated into its constituent hydrogen and oxygen. The hydrogen being light enough easily moves off into space. The net effect of hydrogen loss decreases the amount of water vapor in the atmosphere. A good estimate is that 5×10^{11} grams are lost this way each year. This amounts to a volume of a cube about 100 yards on a side. The total water lost to space since the beginning of the earth thus amounts to about 2×10^{21} grams, about 0.2 percent of the water in the oceans. Fortunately, the same geologic processes that formed the oceans originally replace the water lost to space.

Why is the water still here on the earth? It has to do with the changing nature of the atmosphere due to evolution of life, specifically algae. The algae produced free oxygen by photosynthesis, which destroyed ammonia and methane, so called greenhouse gases, just as the sun's luminosity was increasing by about twenty five percent. If that hadn't happened the oceans would have boiled away long ago. In fact, human beings are the beneficiaries of an incredible balancing act, which allowed just enough heat to escape from the earth to keep the oceans from boiling, but not so much as to cause the earth to freeze solid. Some of the popular theories pointing towards most likely contributing factors to the origin of the Earth's oceans over the past 4.6 billion years are as follows:

1. The cooling of hot gases were released causing "out gassing", potentially bringing water to Earth.
2. Comets, trans-Neptunian objects or water-rich asteroids from the outer reaches of the asteroid belt colliding with a pre-historic Earth may have brought water to the world's oceans. Measurements of the ratio of the Hydrogen

isotopes Deuterium and Hydrogen-1 point to asteroids, since similar percentage impurities in carbon-rich chondrites were found to oceanic water, whereas previous measurement of the isotopes' concentrations in comets and trans-Neptunian objects correspond only slightly to water on the earth.

3. Liquid may have been "locked" in the Earth's rocks and leaked out over millions of years.
4. Photolysis (Radiation can break down chemical bonds separating liquid from hard mass).
5. Rain and sandstorms may have pooled.

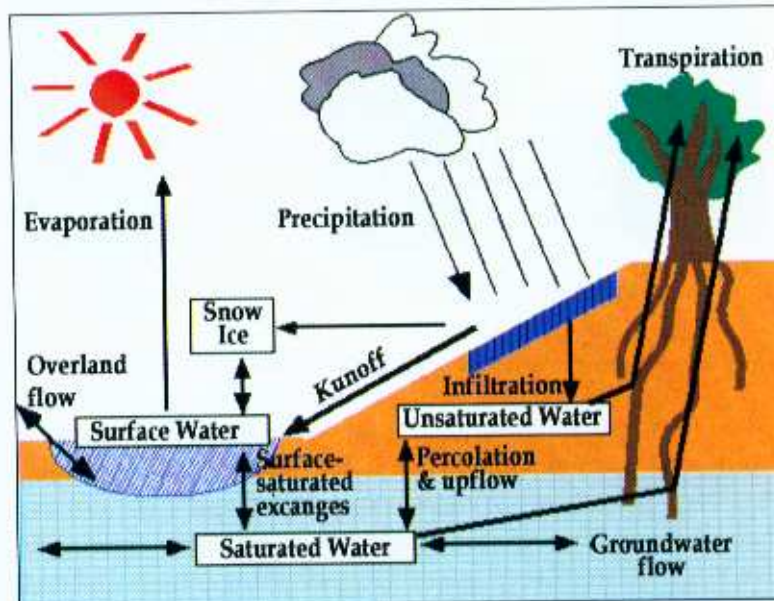
It is quite likely that more than one of these factors contributed to the vast oceans, covering the Earth's surface at the present time. The present coastlines are where they are because some of the water is locked up in the polar ice caps. With this introduction to the origins of our planet, let us now turn to consider how the water exists in/on the earth.

Rain: A valuable resource

Rain and snow are key elements in the Earth's water cycle, which is vital to all life on Earth. Rainfall is the main way through which the water in the clouds comes down to Earth, where it fills the lakes and rivers, recharges the underground aquifers, and provides drinks to plants and animals. Rain does not fall in the same amounts throughout the world or even in different parts of India. What happens to the rain after it falls depends on following factors:

- **The rate of rainfall** - A lot of rain in a short period tends to run off the land into streams rather than soak into the ground.
- **The topography of the land** - Water falling on the land, hills, valleys, mountains, and canyons drains down and becomes part of a stream, a lake, or groundwater.

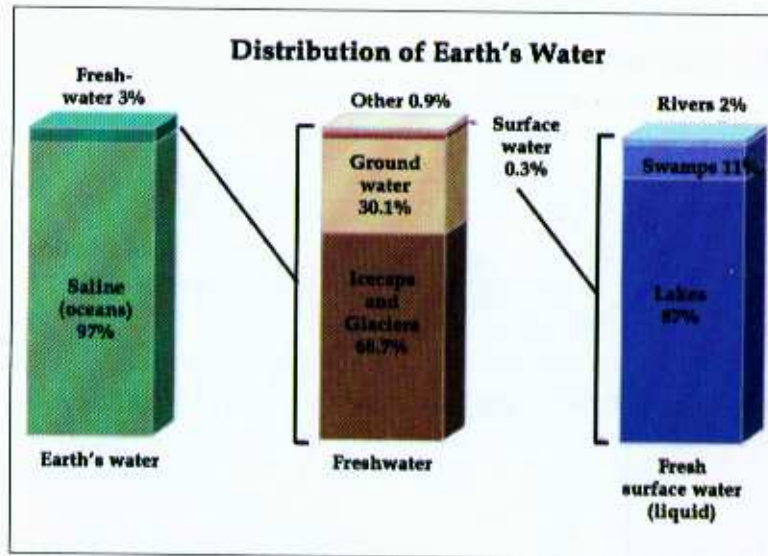
- **Soil conditions** - Dense clay soil makes rain a hard time soaking into, contrast to the sandy soils in desert areas, which allow water to be quickly absorbed.
- **Density of vegetation** - Land with plant cover slows the speed of the water flowing on it and thus helps to keep soil from eroding.
- **Amount of urbanization** - Roads, pavement, and parking lots create impervious areas where water can no longer seep into the ground, causing runoff water.



Where is Earth's water located?

About 70 and 75% of the Earth's surface is water-covered. But water also exists in the air as water vapor and in the ground as soil moisture and in aquifers. The same water that existed on Earth millions of years ago still exists, but, is always in movement, and the water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above,

and below the surface of the Earth. Water can change states among liquid, vapor, and ice at various places in the water cycle, over millions of years. Things would get pretty stale without the water cycle!



When the water around is looked at, water in streams, rivers, and lakes is seen, which is known as "surface water". However, there is much more water stored under the ground than on the surface. In fact, some of the water seen flowing in rivers comes from seepage of ground water into river beds. Water from precipitation continually seeps into the ground to recharge the aquifers, while at the same time water from underground aquifers continually recharges rivers through seepage. The water in the apple eaten yesterday may have fallen as rain half-way around the world last year or could have been used 100 million years ago by Dinosaur to give her baby a bath.

About 97% of all Earth's water is in the oceans. The balance 3% is freshwater. The majority, about 69%, is locked

up in glaciers and icecaps, mainly in Greenland and Antarctica. It may be surprising to know that almost all of the remaining freshwater is below the land surface, as ground water. Of all the freshwater on Earth, only about 0.3 percent is contained in rivers and lakes — yet rivers and lakes are not only the most familiar water, but also the water which is mostly used in everyday lives.

How much water is there on/in the Earth?

In terms of volume, according to the available estimates, the water on earth is distributed as follows:

- 1.35×10^{17} cubic meters (97.3%) Oceans
- 29×10^{15} cubic meters (2.1%) polar ice and glaciers
- 8.4×10^{15} cubic meters (0.6 %) underground aquifers (fresh)
- 0.2×10^{15} cubic meters (0.01%) lakes and rivers
- 0.013×10^{15} cubic meters (0.001%) atmosphere (water vapor)
- 0.0006×10^{15} cubic meters (0.00004%) biosphere.

The role of individual components in Earth's water turnover depends both on the value of water storage and its dynamics. Hydrospheric water of different kinds is fully replenished during this period in the process of hydrological cycle. Its value varies in a very large range. In hydrology and water management, based on water exchange characteristics, the two concepts are often used to assess water resources in a region: the static, or secular, freshwater storage and renewable water resources. The static, or secular, storage includes conventionally the freshwater with the period of full renewal of many years or decades (large lakes, groundwater, glaciers, etc.). The renewable water resources include the water yearly replenished in the process of water turnover on the earth. It is mainly the river runoff estimated in the volume referred to a unit of time (m^3/s , km^3/year , etc.) and formed in the region or

An estimate of global water distribution					
Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of freshwater	Percent of total water	
Oceans, Seas, & Bays	321,000,000	1,338,000,000	—	96.5	
Ice caps, Glaciers, & Permanent Snow	5,773,000	24,064,000	68.7	1.74	
Ground water	5,614,000	23,400,000	—	1.7	
Fresh	2,526,000	10,530,000	30.1	0.76	
Saline	3,088,000	12,870,000	—	0.94	
Soil Moisture	3,959	16,500	0.05	0.001	
Ground Ice & Permafrost	71,970	300,000	0.86	0.022	
Lakes	42,320	176,400	—	0.013	
Fresh	21,830	91,000	0.26	0.007	
Saline	20,490	85,400	—	0.006	
Atmosphere	3,095	12,900	0.04	0.001	
Swamp Water	2,752	11,470	0.03	0.0008	
Rivers	509	2,120	0.006	0.0002	
Biological Water	269	1,120	0.003	0.0001	

incoming from outside, including the groundwater inflow to the river network. This kind of water resources includes also the yearly renewable upper aquifer groundwater not drained by the river systems.

What is river?

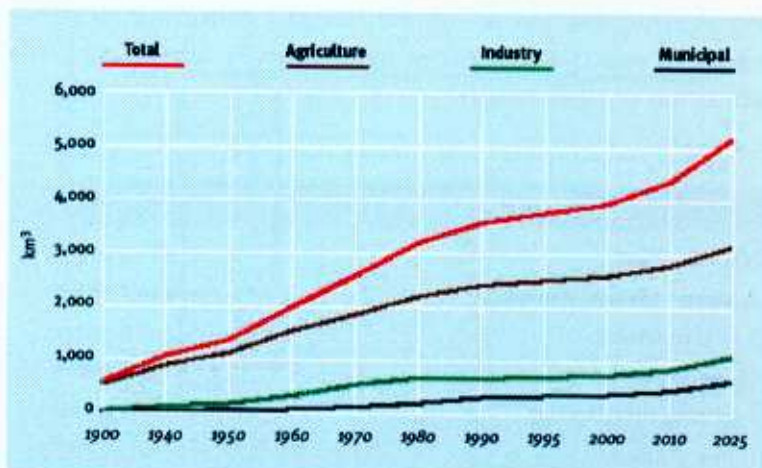
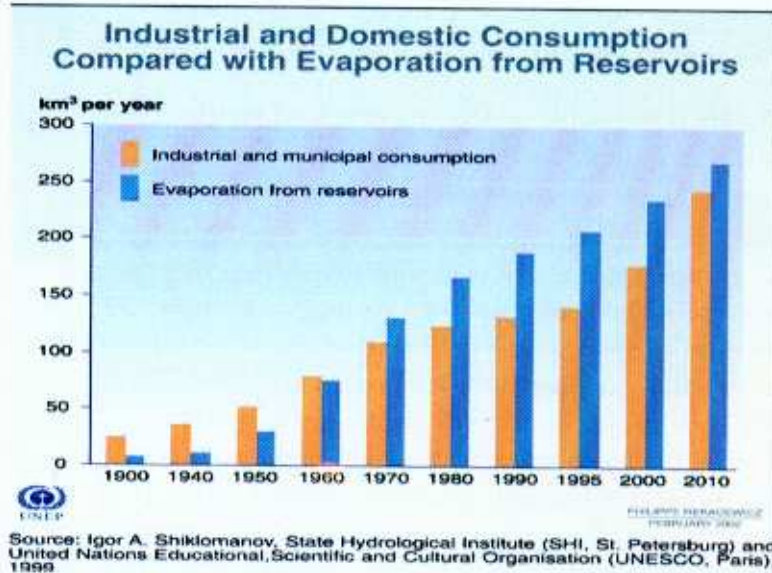
A river is surface water flowing over land, due to gravity, from a higher altitude to a lower altitude. When rain falls on the land, it either seeps into the ground or becomes runoff, which flows downhill initially as small creeks, which merge to form larger streams and rivers, eventually end up flowing into the oceans. When water flows to a place surrounded by higher land on all sides, a lake is formed. If a dam is built to check a river's flow, a reservoir is formed. In the process of turnover, the river runoff is not only recharged quantitatively, but its quality is also restored. So the river runoff, actually represent the renewable water resources. River water is of great importance in the global hydrological cycle and supply of fresh water. River runoff is most widely distributed over the territory and provides the major volume of water consumption in the world. In practice, the water availability is assessed by the estimation of river runoff.

Length of Some Important Rivers		
Nile (Africa)	:	4,132 miles
Amazon (South America)	:	4,087 miles
Yangtze (Asia)	:	3,915 miles
Huang He, aka Yellow (Asia)	:	3,395 miles
Brahmaputra (India)	:	1,800 miles
Indus (India)	:	1,800 miles

(Source: <http://www.nps.gov/rivers/waterfacts.html>, accessed on 9th October, 2006)

World Water Use

The agricultural sector is the largest user of water globally and accounts for about 70% of the total freshwater

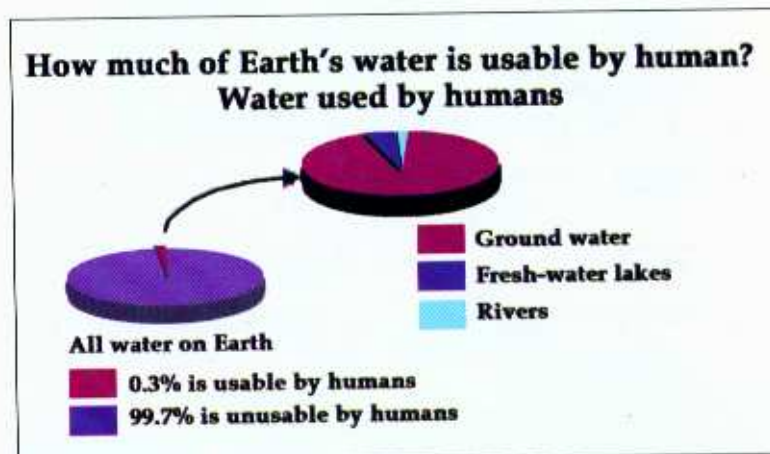


Dynamics of water use (Source: www.unesco.org/courier/2001_10/uk/doss02.htm)

abstraction. Presently, industry accounts for 22% of the global freshwater consumption.

However, water consumption by industries is increasing, and likely to double over the next two decades. In fact, in high-income countries, industrial water use already accounts for as much as 59% of the total fresh water consumption. The volume of water consumed per year by industry is estimated to be 1,170 km³/year by 2025. People, especially in rural areas, are increasingly dependent on groundwater – up to 2 billion people, a third of the world's population rely on it.

The left-side pie chart shows that over 99 percent of all water (oceans, seas, ice, and atmosphere) is not available for our uses. And even of the remaining 0.3 percent (the small brown slice in the top pie chart), much of that is out of reach. Considering that most of the water that is used in everyday life comes from rivers (the small light blue slice in the right-side pie chart), generally, it is only a tiny portion of the available

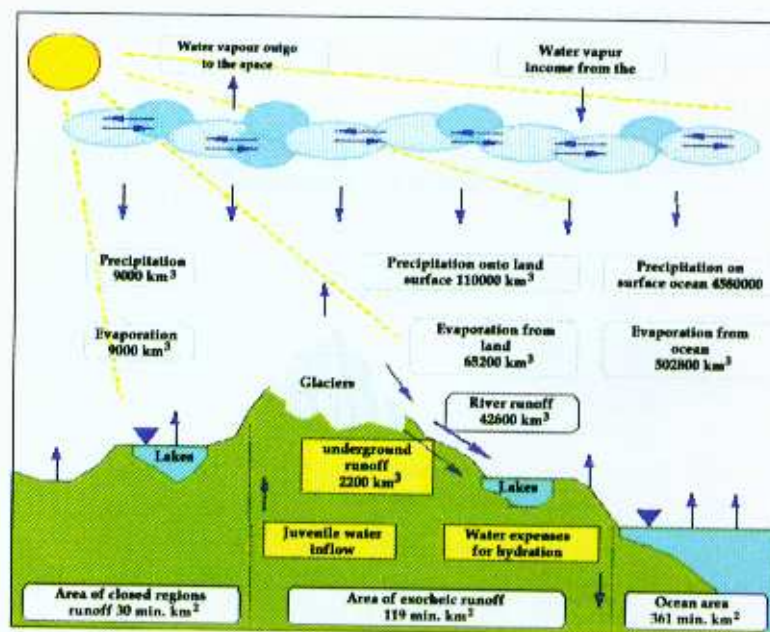


Notice of the world's total water supply of about 1,386 million cubic kilometers, over 96 percent is saline.

water. The right-side pie shows that the vast majority of the fresh water available for our uses is stored in the ground (the large brown slice in the second pie chart).

World Water Turnover

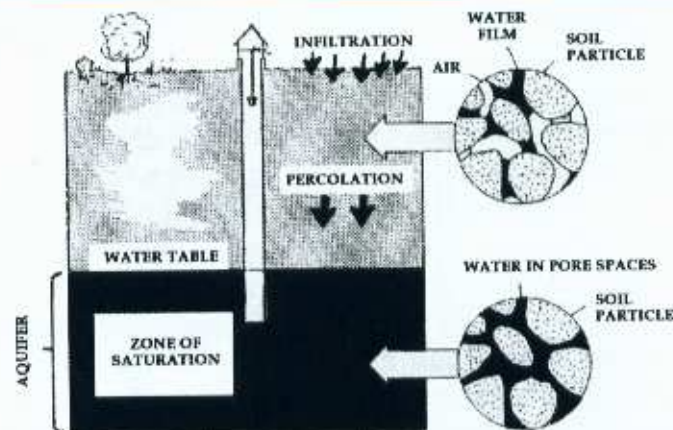
Every year the water turnover on Earth involves $577,000 \text{ km}^3$ of water. It is the water that evaporates from the oceanic surface ($502,800 \text{ km}^3$) and from land ($74,200 \text{ km}^3$). The same water amount falls as atmospheric precipitation (on the ocean $458,000 \text{ km}^3$ and on land $119,000 \text{ km}^3$). The difference between precipitation and evaporation from land surface ($119,000 - 74,200 = 44,800 \text{ km}^3/\text{year}$) represents the total runoff of Earth's rivers ($42,600 \text{ km}^3/\text{year}$), and a direct groundwater runoff to the ocean ($2200 \text{ km}^3/\text{year}$). Base flow for major rivers such as the Mississippi, Niger, and Yangtze comes from groundwater sources.



Schematic diagram of water turnover on Earth

Periods of water resources renewal on the Earth

World Ocean	2500 years
Ground water	1400 years
Polar ice	9700 years
Mountain glaciers	1600 years
Ground ice of the permafrost zone	10000 years
Lakes	17 years
Bogs	5 years
Soil moisture	1 years
Channel network	16 days
Atmospheric moisture	8 days



Water occurrences in the saturated and unsaturated zones of the Geological formations

Biological water several hours

Surfacewater and groundwater pollution effectively decreases the quantity of usable freshwater. Many of the world's lakes, large rivers, and estuaries have been contaminated with anthropogenic effluent discharges. One litre of wastewater pollutes about eight litres of freshwater. Contamination of surfacewater has led many regions of the world to turn to groundwater. An estimated 12,000 km³ of polluted water

worldwide, which is more than the total amount contained in the world's ten largest river basins. Therefore, if pollution keeps pace with population growth, the world will effectively lose 18,000 km³ of freshwater by 2050 - almost nine times the total amount countries currently use each year for irrigation.

What is ground water?

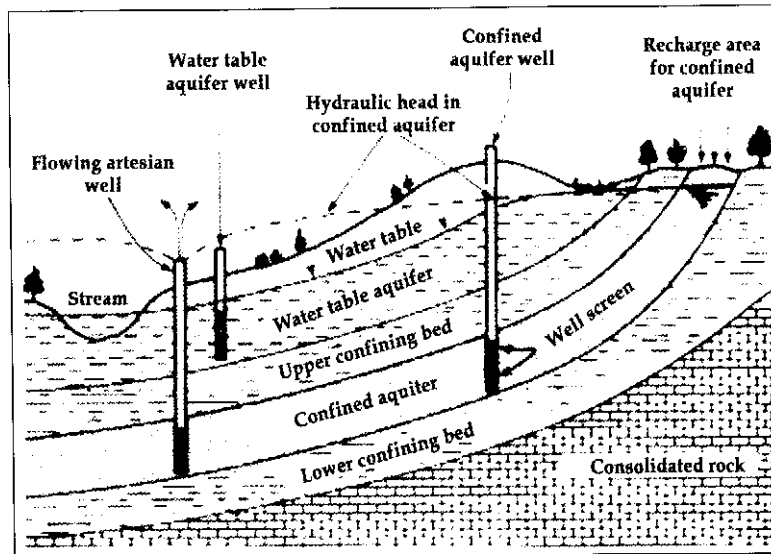
It may probably be some kind of magic for the kids when they pull down a handle of a hand pump and cool freshwater comes out of the ground below their feet. 97% of liquid freshwater is stored underground in aquifers within a few kilometers of the earth's surface almost everywhere, beneath hills, mountains, plains, and deserts. Water at very shallow depths might be just a few hours old; at moderate depth, it may be 100 years old; and at great depth or after having flowed long distances from places of entry, water may be several thousands of years old.. Ground water is an important part of the water cycle, and is the part of rainfall that seeps down through the soil until it reaches rock material that is saturated with water. The ground above the water table may be wet to a certain degree, but it does not stay saturated. The unsaturated zone contains air and some water and support the vegetation on the Earth. The saturated zone below the water table has water filled in the tiny pores between rock particles and the cracks of the rocks.

Why is there ground water?

A couple of important factors are responsible for the existence of ground water:

- (1) **Gravity:** Ground water slowly moves underground, generally at a downward angle (because of gravity), and may eventually seep into streams, lakes, and oceans.
- (2) **The rocks below our feet:** The rock below the Earth's surface is the bedrock. But Earth's bedrock consists of

many types of rock, such as sandstone, granite, and limestone. Bedrocks have varying amounts of void spaces in them where ground water accumulates and can also become broken and fractured; creating spaces that can fill with water. Some bedrock, such as limestone, is dissolved by water — which results in large cavities that fill with water. Most of the void spaces in the rocks below the water table are filled with water. But rocks have different porosity and permeability characteristics, and water does not move around the same way in all rocks.



Gravity doesn't pull water all the way to the center of the Earth. Deep in the bedrock there are rock layers made of dense material, such as granite, or material that water has a hard time penetrating, such as clay. These layers may be underneath the porous rock layers and, thus, act as a confining layer to retard the vertical movement of water. Since it is more difficult for the water to go any deeper, it tends to pool in the porous layers and flow in a more horizontal direction across the aquifer

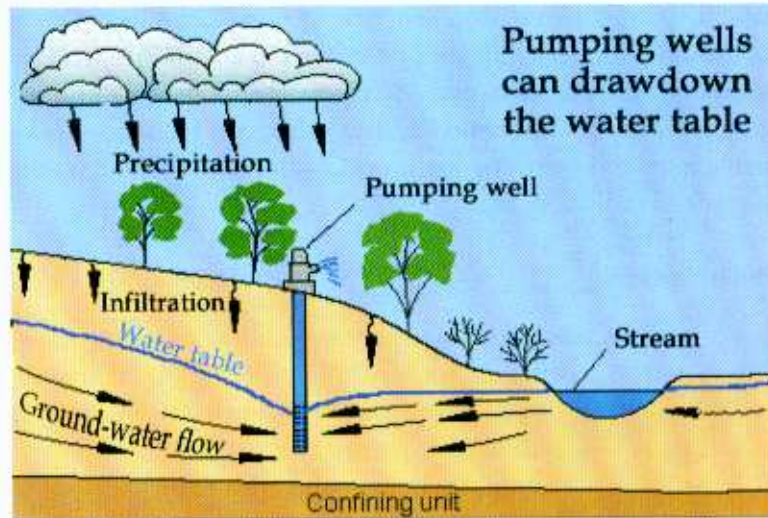
toward an exposed surface-water body, like a river. Often a large amount of the water flowing in rivers comes from seepage of ground water into the streambed, depending on region's geography, geology, and climate. Ground-water pumping can alter how water moves between an aquifer and a stream, lake, or wetland by either intercepting ground-water flow that discharges into the surface-water body under natural conditions, or by increasing the rate of water movement from the surface-water body into an aquifer.

Ground-water aquifers and Water Levels in Wells

When a water-bearing rock readily transmits water to wells and springs, it is called an **aquifer**. Sometimes the porous rock layers naturally remain tilted in the earth. There might be a confining layer of less porous rock both above and below the porous layer. This is an example of a **confined aquifer**. In this case, the rocks surrounding the aquifer confine the pressure in the porous rock and its water. If a well is drilled into this "pressurized" aquifer, the internal pressure might (depending on the ability of the rock to transport water) be enough to push the water up the well and up to the surface without the aid of a pump, sometimes completely out of the well. This type of well is called artesian.

Wells can be drilled into the aquifers and water can be pumped out. Precipitation eventually adds water (recharge) into the porous rock of the aquifer. Seasonal variations in rainfall and the occasional drought affect the "height" of the underground water level. The rate of recharge is not the same for all aquifers, though, and that must be considered when pumping water from a well. Pumping too much water too fast as compared to the recharge rate draws down the water level in the aquifer and eventually causes a well to yield less and less water and even run dry. In fact, pumping a well too fast

can even cause neighbor's well to run dry if both are pumping from the same aquifer. When water levels drop below the levels of the pump intakes, then wells will begin to pump air - they will "go dry".



Ground water serves many purposes

The main uses of ground water include irrigation uses, drinking water and other public uses, and for supplying domestic water to people who do not receive public-supply water. In many areas, the majority of water used for self-supplied domestic and livestock purposes come from ground-water sources. Fresh ground water is used for many important purposes, with the largest amount going toward irrigating crops. Local city water agencies withdraw a lot of ground water for public uses, such as for delivery to homes, businesses, and industries, as well as for community uses such as firefighting, water services at public buildings, and for keeping local residents happy by keeping community swimming pools full of water. Industries and mining facilities also used a lot of ground water.

Broadly categorized sources that can affect water quality

- (a) **Point Sources:** Those readily identifiable at a single location, such as industries, municipal sewage treatment plants, septic tanks, combined sewer overflows and raw sewage discharges.
- (b) **Non-Point Sources:** Those diffuse discharges whose location can not be identified. The main sources are agriculture, forestry, mining, construction, urban run-off, hydrological modifications and residual wastes. Some of the common non-point sources of contaminants are fertilisers, farmyard manure and compost used for

Inorganic contaminants found in ground water		
Contaminant	Sources to ground water	Potential health and other effects
Antimony	Natural minerals, municipal waste, manufacturing of glass, flame-retardants, explosives ceramics, batteries, fireworks,	Decreases longevity, alters blood levels of glucose and cholesterol in laboratory animals exposed at high levels over their lifetime.
Arsenic	Natural processes, industrial waste, pesticides, smelting of copper, lead, and zinc ore.	Causes acute and chronic toxicity, liver and kidney damage; decreases blood hemoglobin.
Barium	Occurs naturally in some lime stones, sandstones, and soils.	Can cause cardiac, gastrointestinal, and neuromuscular effects and hypertension in humans and cardiotoxicity in animals
Beryllium	Soils, rocks, coal, petroleum. Mining operations, processing plants, and waste disposal.	Causes acute and chronic toxicity; damage to lungs and bones. Possible carcinogen.

Cadmium	Found in rocks, coal, and petroleum. Mining waste, metal plating, Industrial discharge, plastic stabilizers, water pipes, batteries, paints, pigments, landfill leachate.	Causes high blood pressure, liver and kidney damage, and anemia. Destroys testicular tissue and red blood cells. Toxic to aquatic biota.
Chloride	Saltwater intrusion, mineral dissolution, industrial and domestic waste.	Deteriorates plumbing, water heaters, and water-works equipment at high levels.
Chromium	Old mining operations runoff, mineral leaching, fossil-fuel combustion, mineral leaching, metal plating, cooling tower water additive, cement-plant emissions, waste incineration.	Chromium VI is much more toxic than Chromium III and causes liver and kidney damage, respiratory damage, internal hemorrhaging, dermatitis, and ulcers on the skin at high levels.
Copper	Metal plating, industrial and domestic waste, mining, and mineral leaching.	Can cause stomach and intestinal distress, liver and kidney damage, anemia in high doses. Imparts an adverse taste and significant staining to clothes and fixtures.
Cyanide	Electroplating, plastics, steel processing, synthetic fabrics, fertilizer production.	Poisoning is the result of damage to spleen, brain, and liver.
Fluoride	Geological minerals; additive to municipal water supplies; industry, phosphate rocks.	High levels can stain or mottle teeth. Causes crippling bone disorder at very high levels.

Iron	Natural mineral, rocks, mining, industrial waste and corroding metal.	Imparts a bitter astringent taste to water and a brownish color to laundered clothing and plumbing fixtures.
Lead	Industry, mining, plumbing, gasoline, coal, and water additive.	Affects red blood cell chemistry; delays normal physical and mental development in babies and young children. Causes slight deficits in attention span, hearing, and learning in children. Can cause slight increase in blood pressure in adults.
Manganese	Natural mineral from sediment and rocks or from mining and industrial waste.	Causes aesthetic and economic damage, imparts brownish stains to laundry. Affects taste of water, and causes dark brown or black stains on plumbing fixtures. Toxic to plants at high levels.
Mercury	Industrial waste, mining, pesticides, coal, electrical equipment (batteries, lamps, switches), smelting, and fossil-fuel combustion.	Causes acute and chronic toxicity. Targets the kidneys and can cause nervous system disorders.
Nickel	Electroplating, stainless steel and alloy products, mining, and refining.	Damages the heart and liver of laboratory animals exposed to large amounts over their lifetime.
Nitrate; Nitrite	Natural mineral deposits, soils, seawater, freshwater systems, atmosphere, biota, fertilizer, feedlots, and sewage.	Causes "blue baby disease," or methemoglobinemia, which threatens oxygen-carrying capacity of the blood.

Selenium	Naturally occurring geologic sources, sulfur, and coal.	Causes acute and chronic toxic effects in animals—"blind staggers" in cattle. Toxic at high doses.
Silver	Ore mining and processing, photography, electroplating, alloy, solder product fabrication and disposal.	Can cause argyria, a blue-gray coloration of the skin, mucous membranes, eyes, and organs in humans and animals with chronic exposure.
Sulfate	Saltwater intrusion, mineral dissolution, and domestic or industrial waste.	Forms hard scales on boilers and heat exchangers; can change the taste of water, and laxative effect in high doses.
Thallium	Electronics, pharmaceuticals manufacturing, glass, and alloys.	Damages kidneys, liver, brain, and intestines in laboratory animals when given in high doses over their lifetime.
Zinc	Industrial waste, metal plating, plumbing, and sludge.	Imparts an undesirable taste to water. Toxic to plants at high levels.
Organic contaminants found in ground water		
Contaminant	Sources to ground water	Potential health and other effects
Volatile organic compounds	Industries of plastics, dyes, rubbers, polishes, solvents, crude oil, insecticides, inks, varnishes, paints, disinfectants, gasoline products, pharmaceuticals, preservatives, spot removers, paint removers, degreasers, and many more.	Can cause cancer and liver damage, anemia, blurred vision, gastrointestinal disorder, skin irritation, exhaustion, weight loss, nervous system damage, and respiratory tract irritation.

Pesticides	Herbicides, insecticides, fungicides, rodenticides, and algicides.	Cause poisoning, numbness, weakness, cancer, headaches, gastrointestinal disturbance, dizziness. Destroys nervous system, thyroid, reproductive system, liver, and kidneys.
Plasticizers, chlorinated solvents, benzo [a] pyrene, and dioxin	Waste disposal, leaching runoff, leaking storage tank, and industrial runoff of sealants, linings, solvents, pesticides, plasticizers, components of gasoline, disinfectant, and wood preservative.	Cause cancer. Damages nervous and reproductive systems, kidney, stomach, and liver.

Microbiological contaminants found in ground water

Coliform bacteria	Occur naturally in soils and plants; in the intestines of humans and other warm-blooded animals.	Bacteria, viruses, and parasites can cause polio, cholera, typhoid fever, dysentery, and infectious hepatitis.
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Radiological contaminants found in ground water

Gross alpha-particle activity; Beta-particle and photon radioactivity	Weapons, nuclear reactors, medical treatment and diagnosis, mining radioactive material, and radioactive geologic formations.	Damages tissues and destroys bone marrow.
Combined radium-226 and radium-228	Historical industrial-waste sites are the main man-made source.	Causes cancer in the bone and skeletal tissue.

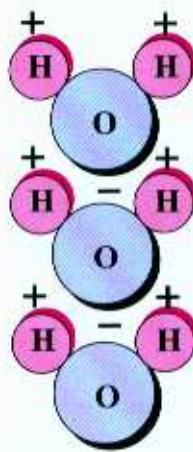
agricultural purposes, and land-disposed industrial effluents from brick kilns, plating, galvanising, rayon manufacture, rubber processing, pickling, and iron and steel production. Regular applications of nitrogenous fertilisers, phosphate fertilisers (which contain ~1-3% F), fumigants, rodenticides, insecticides and herbicides containing fluoride as impurity or constituent, and other such agrochemicals, as well as indiscriminate disposal of wastes, are likely to create a blanket non-point source of contaminants.

A wide variety of chemical and physico-chemical processes, such as, denitrification, precipitation, dissolution, hydrolysis, transformation/degradation, complex formation, redox equilibria, colloid formation, diffusion, dispersion, convection and sorption/desorption, can be expected to alter the quality of groundwater. In a watershed, gradients in groundwater quality and contaminant levels can have a variety of configurations, depending locally on both transient and steady state variables, such as geological, geomorphological, hydrological, mineralogical, depth to confinement, weathering history and other related features. These include: (1) changes in contaminants concentration in recharging groundwaters over time, and (2) the distance, direction and time between recharge and discharge of contaminated groundwaters, and the distribution and effectiveness of natural remediation.

Water properties

Pure water is virtually colorless and has no taste or smell. But the qualities of water make it a most interesting. Water's chemical description is H_2O that is one atom of oxygen bound to two atoms of hydrogen. The hydrogen atoms are "attached" to one side of the oxygen atom, resulting in a water molecule having a positive charge on the side where the hydrogen atoms are and a negative charge on the other side, where the oxygen

atom is. Due to opposite electrical charges, water molecules attract each other, and tend to clump together making it kind of "sticky." The side with the hydrogen atoms (positive charge) attracts the oxygen side (negative charge) of a different water molecule. This is why water drops are, in fact, drops! Water's melting and boiling points are higher than that of similar compounds. It is unusually viscous based on its comparatively small molecular weight. Water has the ability to act as either an acid or a base depending on the circumstances, and by its nature it is perfectly neutral.



Water molecules attract each other due to opposite electrical charges

Though polar in its make up, it exhibits properties that indicate a sort of polymerizing link between its molecules. While it exists on earth in all three basic states, solid, liquid, and gas; water's properties are often bizarre by most standards. For example liquid water contracts when cooled until it reaches a temperature of about 4°Celsius where it reaches its maximum density. When this temperature is reached liquid water begins to expand, and even with a change in state to ice, water continues to expand, by reducing its density as its temperature decreases. Water reacts with more substances than any other compound. It reacts physically with several compounds to add to their crystal structure. Compounds like copper and magnesium sulfate are two examples of many compounds that almost always found in nature with water molecules physically attached to their crystal structure. These compounds are natural dehumidifiers, dependent on water to complete their structure. Many organic compounds get their oxygen and/or hydrogen from reactions with water. Water molecules have a unique ability to be energized by microwave radiation, and at the same

time make an excellent barrier to nuclear radiation. It absorbs neutrons in nuclear power plants, yet is easily heated by microwaves.

Water is a solvent

Water is called the “universal solvent” because it dissolves more substances than any other liquid. When water is the solvent, the solution is said to be an aqueous solution. In water, the molecules are held close together by hydrogen bonding that cause water to exist as a liquid at the temperatures and pressures that normally prevail on the Earth’s surface. Life depends on this property. Since there is so much water in living organisms, water is a very important solvent. Substances such as glucose dissolve in the water of the blood, which allows it to be carried around the human body. In plants, the most commonly transported substance is sucrose, which is also soluble in water. Water plays a very significant role in our sleeping course. Our body is mostly made up of water, and it will not function well if there is insufficient supply of it in the system. In a day, 10 to 12 cups of water is lost from our body! So, if the water lost is not replaced, blood clusters together and becomes powerless to carry adequate amount of oxygen to all parts of the body, making the body feel frail, declining the ability to ponder or think well, and reducing the energy level at minimum. Worst of all, it would lower the body’s resistance against stress, sickness, or diseases as a result of a weak immune system. If the body is dehydrated, blood flow to our fundamental organs would dwindle during sleep. Furthermore, having an adequate amount of water in the body helps normalize the body temperature rhythm.

Thermal capacity

Water is also extremely useful due to its high heat capacity; that is, a large amount of heat energy is required to raise the

temperature of water. It has an enormous ability to absorb and transmit energy, because, much of the energy is used to break the hydrogen bonds, which restrict the mobility of the molecules. As a result, water is relatively slow to heat up or cool down. In fact, the specific heat capacity of liquid water is the highest of any known substance. The latent heat (enthalpy) of fusion of water (the heat energy needed to melt ice) is unusually high. Therefore, relatively large amounts of heat energy must be extracted from liquid water before it freezes. For example, the amount of energy to melt 1 kg of ice at 0°C would be enough to lower the temperature of 1 kg of Aluminum over 570°C . The latent heat of vaporisation of water (the heat energy required to vaporise liquid water) is also unusually high, and thus has a remarkable cooling effect. Most liquids contract on cooling, reaching their maximum density at their freezing point. Water is unusual in reaching its maximum density above its freezing point - at 4°C . So when water freezes the ice formed is less dense than water and floats on top. Ice on the surface effectively insulates the water below, thereby making it less likely that the bulk of water (sea, pond or lake) will freeze up even if the air above is very cold. This prevents large bodies of water from freezing solid and contributes to the survival of aquatic organisms.

Cohesion, Adhesion, surface tension and capillarity

The hydrogen bonding of water results in strong cohesive forces. Due to this, the surface of a water drop assumes the smallest possible area, and forms a sphere. At the surface of water, the molecules are orientated such that most hydrogen bonds point inwards towards other water molecules. This gives water a very high surface tension, higher than any other liquid except mercury. The ability of water to cling readily to other molecules is responsible for the upward movement of water

when a small-bore tube is dipped into it. This phenomenon is called capillarity. Theoretically, plant xylem vessels (dia. 0.02mm) can support a water column of height 1.5m by capillarity forces. One of its main biological effects is the upward movement of water in the soil. Without sufficient water at appropriate time most new technological inputs such as HYVs, fertilizers are relatively ineffective. Water shortages severely affect crops by reducing seed germination, seedling emergency, photosynthesis, respiration, leaf number and seed number and seed filling. Water stress limits the limits the metabolism of nitrogen and other nutrients in crops.

Water Facts

- Most of the earth's surface water is permanently frozen or salty. Complete melting of polar ice caps would rise the oceans about 240 ft above its present level.
- If all the world's water were fit into a gallon jug, the fresh water available for us to use would equal only about one tablespoon.
- Showering, bathing and using the toilet account for about two-thirds of the average family's water usage.
- The average person needs 2 quarts of water a day.
- Approximately 66% of the human body consists of water.
- The total amount of water in the body of an average adult is 37 litres.
- Human brains are 75% water; Human bones are 25% water.
- Human blood is 83% water.
- A person can live about a month without food, but only about a week without water. If a human does not absorb enough water dehydration is the result.

- A person must consume 2 litres of water daily to live healthy. Humans drink an average of 75,000 litres of water throughout their lives.
- It takes enormous amount of water to produce crops: one to three cubic metres to yield just one kilo of rice, and 1,000 tons of water to produce one ton of grain.
- About 6,800 gallons of water is required to grow a day's food for a family of four.
- 1000 tons of water is required to produce one ton of wheat.
- 2,000 tons of water is required to produce one ton of rice.
- 95% of a tomato is water. 85% of a potato is water. 80% of a pineapple is water.
- Each day the sun evaporates a trillion tons of water.
- A single tree will give off 265 liters of water per day in evaporation.
- An acre of corn will give off 15,000 litres of water per day in evaporation.
- It takes almost 49 gallons of water to produce just one eight-ounce glass of milk. That includes water consumed by the cow and to grow the food she eats, plus water used to process the milk.
- A small drip from a faucet can waste as much as 75 litres of water a day.
- Humans daily use about 190 litres of water.
- Two thirds of the water used in a home is used in the bathroom.
- To flush a toilet we use 7.5 to 26.5 litres of water.
- In a five-minute shower we use 95 to 190 litres of water.
- To brush your teeth you use 7.5 litres of water.
- Only 30 per cent of the world's people have a guaranteed supply of treated water. The remaining 70 per cent depend

on wells; bore holes and other uncertain sources of water supply, all liable to contamination.

- In a 100-year period, a water molecule spends 98 years in the ocean, 20 months as ice, about 2 weeks in lakes and rivers, and less than a week in the atmosphere.
- Amount of time that groundwater, once polluted, can remain polluted: several thousand years.

Source: <http://www.nps.gov/rivers/waterfacts.html>; <http://www.lenntech.com/water-trivia-facts.htm> (accessed on 9th October, 2006)

- In Africa, agriculture consumes 88% of all water, while domestic use accounts for 7% and industry for 5%. In Europe, 54% of water is used in industry, 33% in agriculture and 13% for domestic use.
- Almost 70% of all available freshwater is used for agriculture. Current global water withdrawals for irrigation are estimated at about 2,000 to 2,555 cubic kilometres per year.
- Pumping of groundwater by the world's farmers exceeds natural replenishment by at least 160 billion cubic metres a year.
- Agriculture is responsible for most of the depletion of groundwater, along with up to 70 per cent of the pollution. Both are accelerating.
- Many of the world's most important grainlands are consuming groundwater at unsustainable rates. Collectively, annual water depletion in India, China, the United States, North Africa and the Arabian Peninsula adds up to 160 billion cubic metres a year.
- In developing countries, 70% of industrial wastes are dumped untreated into waters where they pollute the usable water supply.

- More than one billion people on earth already lack access to fresh drink water. If current trend persists, by 2025, the demand for freshwater is expected to rise to 56%, exceeding the amount that is currently available.
- By 2000, available freshwater per person dropped to 7,800 cubic metres from 9,000 cubic metres in 1989, and is expected to plummet to 5,100 cubic metres per person by 2025, when the global population is projected to reach 8 billion.
- The world's six billion people are already using about 54% of all the accessible freshwater contained in rivers, lakes and underground aquifers. By 2025 the human's share will be 70%, based on the population increase.
- If per capita consumption of water resources continues to rise at its current rate, humankind could be using over 90% of all available freshwater within 25 years.
- By 2025, according to projections, more than 2.8 billion people in 48 countries will be facing water stress or scarcity.
- By 2050, the number of water short countries soars to 54, affecting 4 billion people, or 40% of the projected global population. The worst hit areas are in the Middle East, North Africa and in sub-Saharan Africa.
- Over 200 million sub-Saharan Africans already live in water short countries. This figure will increase to 700 million by 2025, of whom over half will live in countries facing severe shortages for most of the year.

Source: <http://www.ozh2o.com/h2use.html> (accessed on 19th October, 2006)



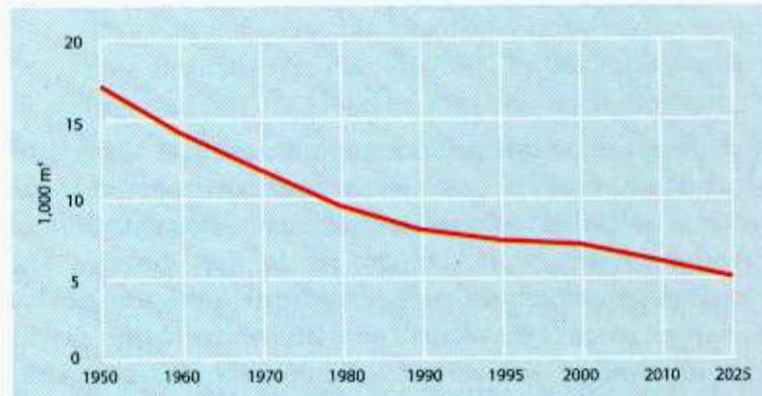
International Scenario

Water resources distribution over the territory of the Earth is uneven. The total water resources renewal in the world is estimated of the order of $43750 \text{ km}^3/\text{year}$, distributed throughout the world according to the climates and physiographic structures. At the continental level, America has the largest share of the world's total freshwater resources with 45%, followed by Asia with 28%, Europe with 15.5% and Africa with 9%. The largest renewable water resources are concentrated in six principal countries of the world: Brazil, Russia, Canada, USA, China, and India. Nine countries are the world giants in terms of internal water resources, accounting for 60% of the world's natural freshwater. In terms of absolute value, the largest exploitable renewable water resources are characteristic of Asia and South America (respectively, $13,500$ and $12,000 \text{ km}^3$ per year). The smallest are typical for Europe and Australia with Oceania (respectively, 2900 and 2400 km^3 per year). For individual years, the values of water resources can vary in the range of $\pm 15\text{-}25\%$ of their average values. The specific water availability, i.e., actual per capita renewable water resources without water consumption, decreases as population and water consumption grow.

(Note: $1 \text{ km}^3 = 109 \text{ m}^3 = 1 \text{ billion cubic metre (BCM)} = 0.10 \text{ million ha m.}$)

Due to rapid growth in Earth's population since 1970 to 1994, the potential water availability of Earth's population decreased from 12.9 to 7.6 thousand m^3 per year per person. The greatest reduction of per capita water supply took place in Africa (by 2.8 times), Asia (by two times), and South America (by 1.7 times). The water supply of European population decreased for that period only by 16%. About 60-70% of this runoff is mainly formed during the flooding

Global water availability per person



(Source: www.unesco.org/courier/2001_10/uk/doss02.htm)

period. In terms of resources per inhabitant in each continent, America has 24000 m^3 /year, Europe 9300 m^3 /year, Africa 5 000 m^3 /year and Asia 3 400.1 m^3 /year. At country level, there is an extreme variability: from a minimum of 10 m^3 /inhabitant in Kuwait to more than 100000 m^3 /inhabitant in Canada, Iceland, Gabon and Suriname. For 19 countries or territories, the water resource per inhabitant are less than 500 m^3 ; and the number of countries or territories with less than 1000 m^3 /inhabitant is 29. The ten poorest countries in terms of water resources per inhabitant are Bahrain, Jordan, Kuwait, Libyan Arab Jamahiriya, Maldives, Malta, Qatar, Saudi Arabia, United Arab Emirates and Yemen.

The information on the specific water availability, for all economic regions and selected countries for the 1950-2025 period, suggest that e.g., the greatest water availability of 170-180 thousand m³ per capita for 1995 was in the regions of Canada with Alaska and in Oceania. At the same time, in densely populated regions of Asia, Central and South Europe, and Africa the present water availability is within 1.2-5 thousand m³ per year. In the north of Africa and on the Arabian Peninsula, it is as much as 0.2-0.3 thousand m³ per year. It is worth mentioning that water availability of less than 2000 m³ per year per capita is considered to be very low, and less than 1000 m³ per year catastrophically low. The thresholds of 1000 and 500 m³/inhabitant correspond respectively to water stress and water scarcity levels.

Regional Overview

In general, the water resources estimated on the basis of surface water flows, the countries of the world could be broadly grouped into ten regions composed of various sub-regions. Of most importance for water supply is the basic runoff; which is stable, with little variation during a year and year-to-year. Its value is approximately 37% of the total volume of global river runoff, or about 16,000 km³ per year. Many regions are characterized by an extremely uneven river runoff distribution, and 60 to 80% of annual runoff takes place during 3-4 months. For instance, 64% of annual runoff passes during three flooding months in the north and south of the European part of the Former Soviet Union (FSU); 57% in the central part of North America and in southern Asia; 59% in Siberia and the Far East; 68% in Australia, and 80% in western Africa. While, the river runoff for the low flow period, lasting 3-4 months, amounts to only 8-9% of annual runoff in the north of the European territory of the FSU, Canada and Alaska, North China and

Mongolia; 6.7% in Central America; 4-5% in Siberia and the Far East, and Southern Asia, and as much as 0.8% in Western Africa. In almost all regions of the world, unevenness of river runoff distribution during a year leads to the necessity of its regulation by creating reservoirs of different types.

Region 1: Northern America - The region, extending over about 21 million km², covers 16% of the world's land area, and can be divided into three subregions: (i) Alaska, Canada and Greenland; (ii) Mexico; and (iii) The United States of America (conterminous states). Overall, the region is relatively well endowed with water resources. In Alaska, the annual precipitation ranges from 1524 to 3810 mm with estimated natural runoff at 8,01,540 million m³/year to less than 127 mm in the arctic region. Canada (area of 9.98 million km²), the second largest country in the world has about 9% of the world's freshwater resources. Freshwater bodies cover 7.6% of its area. The annual precipitation decreases in a northerly direction from 500 mm in the central area to 125 mm in the arctic islands. Canada has more than 31,000 freshwater lakes, ranging from 3 km² to more than 100 km². The Great Lakes store 22,700 km³ of freshwater, 99% of which is a remnant from the glacial period and so non-renewable. The United States of America has total area of 9.36 million km², and taken as a whole, the conterminous states receive an average of about 762 mm of precipitation annually. This region is the home to 7% of the world's population; the water resources per person exceed 16000 m³/year, much higher than the world average.

Region 2: Central America and Caribbean - The region, occupying about 0.73 million km² or 0.6% of the world's total land area, can be divided into the following subregions: (i) Central America, occupying 72% of the region, with precipitation increasing from north to south and from west to east; and (ii) Caribbean (total area of 0.19 million km²)

Renewable water resources and water availability by continents

Continent	Area, million km ²	Population (million)	Water resources, (km ³ /year)			Potential water availability, 1000m ³ /year	
			Average	Max	Min	per capita	per
Europe	10.46	685	2900	3410	2254	277	4.23
North America	24.3	453	7890	8917	6895	324	17.4
Africa	30.1	708	4050	5082	3073	134	5.72
Asia	43.5	3445	13510	15008	11800	311	3.92
South America	17.9	315	12030	14350	10320	672	38.2
Australia and Oceania	8.95	28.7	2404	2880	1891	269	83.7

consisting of the islands: Greater Antilles and the Lesser Antilles. The average annual rainfall in the subregion is 1141 mm. The region is relatively well endowed with water resources, and receives 1.4% of the world's precipitation and generates 1.8% of its water resources. With 1.1% of the world's population, the water resource per person in the region is estimated at about 11,900 m³/year, about double the world average.

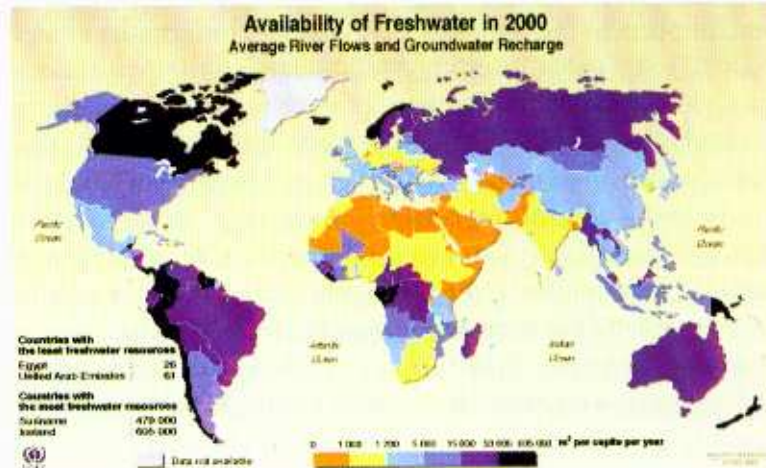
Region 3: Southern America - The region, covering about 17.8 million km² or 13% of the world's total land area, can be subdivided into the following subregions: (i) Guyana; (ii) Andean; (iii) Brazil; (iv) Southern. The Guyana occupies 0.47 million km² (2.1% of the region's total area) and precipitation is highest in the south, 1500-2400 mm/year. The Andean subregion covers 4.72 million km² and precipitation increases towards the north. Brazil (area 8547 million km²) covers 48% of the region and the south of this subregion has rainfall of 1250-2000 mm/year and in the southeast, the rainfall ranges from 900-4400 mm/year; the central-west has an average annual rainfall of 1250-3000 mm/year. The northeast has an average annual precipitation, irregularly distributed, of 750 mm to less than 250 mm. The north (with an average 1500-3000 mm/year of rainfall) covers almost the whole of the Amazon River basin. The Southern subregion total area is 4.1 million km² (23.2% of the region's total area). Overall, the region is relatively well endowed with water resources, receiving 26% of the world's precipitation and generating 28% of its water resources. Home to 5.7% of the world's population, the water resource per person in the region is about 35,000 m³/year, well above the world average. Chile presents an annual water availability of 63064 m³/inhabitant. Climate characteristics of the Central and Southern America generate strong inter-seasonal and inter-annual variation in water resources, aggravated by meteorological phenomena such as El Niño.

Region 4: Western and Central Europe - The region, occupying about 3.7% of the world's total land area and having 8.4% of its population, can be divided into four subregions: (i) Northern Europe; (ii) Western Europe; (iii) Central Europe; and (iv) Mediterranean Europe. Overall, water resources are abundant, with about 2200 km³ in an average year (5% of the world's water resources) and 4270.4 m³/inhabitant/year, but unevenly distributed among countries. The distribution of precipitation in the region is very diverse, ranging from less than 300 mm/year in many Mediterranean plains to more than 3000 mm/year on the coast of the Norwegian Sea. There are seven main watersheds of more than 1,00,000 km². The major one is the Danube Basin (about 8,00,000 km²), which covers about 17% of the region. On average, river runoff is about 450 mm/year, varying from less than 50 mm/year in areas such as southern Spain to more than 1500 mm/year in various areas of the Atlantic coast and of the Alps. The Danube River has the largest flow, 205 km³/year. A wide inter-annual and seasonal variations in runoff characterize the region's rivers.

In 2000, renewable water resources per inhabitant ranged from less than 40 m³/year in Malta and 992 m³/year in Cyprus to 1140 m³/year in Denmark, 85,500 m³/year in Norway and more than 6,00,000 m³/inhabitant in Iceland. Some countries rely heavily on external water resources and would fall under the threshold of 1000 m³/inhabitant/year if they had to rely only on their internal resources: Hungary (less than 600 m³/inhabitant/year), and the Netherlands (less than 700 m³/inhabitant/year). The Northern Europe has very abundant water resources per country and per inhabitant (except Denmark) and its drainage systems are quite large. The Western Europe has relatively small rivers. The Mediterranean Europe has a higher level of water resources per inhabitant than the Western Europe and Central Europe subregions. However, the

water resources are unevenly distributed in numerous small basins, among and within countries.

Region 5: Eastern Europe - The region (total area about 18 million km²) includes the Russian Federation and the eastern European and Baltic states, covering 13.5% of the world's land area and accounting for 3.6% of its population. The regional



Source: *World Resources 2000-2001*, People and Ecosystems: The Fraying Web of Life, World Resources Institute (WRI) Washington DC, 2000.

water availability is characterized by an extreme variability: from a minimum of 227 m³ per inhabitant in the Republic of Moldova to more than 29,000 m³ per inhabitant in the Russian Federation. However, the water resources in the Russian Federation are very unevenly distributed. In the more densely populated western part, annual renewable surface water resources are estimated at about 2000 m³/inhabitant compared with up to 1,90,000 m³/inhabitant in the Siberian and Far Eastern regions. Adding the external flow, all the countries of the Eastern Europe region show total actual renewable water resources in excess of 2000 m³/inhabitant. Three countries depend on other countries for renewable water resources: the

Republic of Moldova for more than 91%, Ukraine for 62%, and Latvia for 53%. All other countries in the region have more than 2000 m³/inhabitant/year and four countries have more than 10,000 m³/inhabitant/year.

Region 6: Africa – The region, occupying 22.4% of the world's land area, and 9% of the world's water, can be divided into seven climatic subregions on the basis of geography: Northern Africa; Sudano-Sahelian; Gulf of Guinea; Central Africa; Eastern Africa; Indian Ocean Islands; Southern Africa. Northern Africa has very limited water resources, with less than 10 mm/year on average and faces very severe water scarcity, with values per inhabitant varying between 200 and 700 m³/year. In terms of internal water resources, it is the poorest subregion in Africa (1.2% of the continent's total internal water resources) and it is the subregion with the highest percentage of external water resources (63%) due to the Nile River, which serves only one country. However, the Sahara has very important fossil groundwater reserves of major sedimentary aquifers.

The Gulf of Guinea internal resources represent 25% of the continent's total water resources, and groundwater accounts for 30-50% of the subregion's total water resources. In the Central Africa, with abundant water resources, represent 48.4% of the continent's internal resources and is a major provider of water to neighbouring subregions. The Eastern Africa has the Africa's largest lake (Lake Victoria), yet, the water resources are limited (6.5% of the continent's internal resources) In terms of water resources, after the Democratic Republic of Congo, Madagascar is the continent's second richest country. The other small islands have abundant groundwater resources, scattered within their territories. The Southern Africa has various major trans-boundary river basins, and the water resources constitute 7% of the continent's total. With only 13% of the world's

population, the region's water availability is 4979 m³/inhabitant/year. Considering the region as a whole, transfers of water from humid to arid zones represent 50% of the water resources of the arid zones. Another specificity of the region is the non-renewable important groundwater reserves located in the large sedimentary aquifers systems (Continental aquifer, Nubian sandstones, Sahel and Chad watersheds, Kalahari, etc.), with reserves estimated to be many thousand million cubic metres. The Libyan Arab Jamahiriya depends heavily on fossil groundwater to cover its current water demand.

Region 7: Near East - The region can be divided into subregions: (i) Arabian Peninsula; (ii) Caucasus; (iii) Middle East. The Near East region covers an area of 6.34 million km² and includes 250 million people. The region has the lowest per capita water resources. Precipitation in the region is very low and variable, and the water resources are particularly sensitive to drought. While the Near East region covers 4.7% of the world's total land area, the water resources are only about 1.1% of the world's water. The countries of the Near East region have less water resources per person than the world average. The Arabian Peninsula has very limited water resources, with less than 10 mm/year of rainfall on average, and is in a situation of very severe water scarcity, with 200 to 700 m³/inhabitant/year. Some oil-rich countries convert saline water from the sea or from poor-quality aquifers (brackish water) into drinking water. The total use of desalinated water in the Near East region is estimated to be 3.93 km³/year. In absolute terms, Saudi Arabia, the United Arab Emirates, and Kuwait are by far the largest users of desalinated water, accounting for 77% of the total for the region.

Region 8: Central Asia - The region can be divided into two subregions: Aral Sea countries; and Other countries. Although the region covers 3.5% of the world's total land area

and contains 1.3% of its population, its water resources are only about 0.7% of the world's WR. The average annual renewable surface water resources in the Aral Sea Basin are estimated at 116 km³, of which 78 km³ in the Amu Darya Basin and 37 km³ in the Syr Darya Basin. The present day inflow to the Aral Sea is estimated at 1-2 km³/year from the Syr Darya and 5-10 km³/year from the Amu Darya.

Region 9: Southern and Eastern Asia - The region occupies about 20.4 million km², or 15% of the world's total land area. China and India combined together account for about 63% of this area. The region can be divided into five subregions as follows: (i) Indian Subcontinent; (ii) Eastern Asia; (iii) Far East; (iv) Southeast Asia; and (v) Islands. In the Indian Subcontinent (area of 3.96 million km², or about 18% of the region's total area), consisting of a large portion of floodplains along the Indus and Ganges river basins, about 80% of the total precipitation occurs during the two monsoon periods: the southwest monsoon (June-September), which brings most of the rainfall; and the northeast monsoon (November-March). The average annual precipitation in the subregion is about 1279 mm, varying from less than 150 mm in the northwest desert of Rajasthan, India, to more than 10 m in the Khasi Hills in northeast India.

In the Eastern Asia (area 11.3 million km² or about 55% of the region's total area and 8.4% of the world's total land area), the average annual precipitation is 597 mm, varying from less than 25 mm in the Tarim and Qaidam basins in China to 1520 mm in DPR Korea. In the Far East subregion (area is 0.48 million km² or 2% of the total area of the region), the average annual precipitation is 1634 mm, most falling during the summer months from June to September. In the Southeast Asia (area 1.94 million km², or 9.5% of the total area of the region), the average annual rainfall is 1877 mm, ranging from 500 mm in

the central dry zone in Myanmar and 650 mm in Phan Rang in Viet Nam to more than 4000 mm in the mountains of Rakhine in Myanmar and Bac Quang in Viet Nam. In the Islands subregion (3.0 million km², or about 15% of the area of the region), the average annual rainfall is 2823 mm, ranging from less than 1000 mm in Port Moresby to more than 8000 mm in some mountainous areas in Papua New Guinea.

The region has quite humid climates (with annual precipitation above 10 m) in some places and in other parts, a very arid climate. As a result, the region shows a very uneven distribution and use of its water resources. In India, the flow distribution of selected rivers in the monsoon period represents 75-95% of the total annual flow. In north China, 70-80% of the annual runoff is concentrated in the rainy season. Overall, the region is relatively well endowed with water resources. While occupying 15.8% of the world's land surface, it receives 22% of its precipitation and produces 27% of its water resources. However, in terms of water resources per inhabitant, the Indian Subcontinent, Eastern Asia and Far East subregions show the lowest figures while the figures for the Southeast Asia and Islands subregions are considerably higher than the world average.

Region 10: Oceania and Pacific - The region covering an area of 8 million km² or 6 % of the world's total land area, can be subdivided into two subregions: Australia: Australia; and Other countries. The countries of this region are mostly islands of very different types. Some of the islands have a tropical climate governed mainly by the change between the wet season, with heavy rainfall, and the dry season. About 75% of the total rainfall occurs during the wet season. This results in a large difference in the water level in rivers between the wet and the dry seasons. The large islands such as Australia and New Zealand have very dry to humid climates. Australia is dry, with

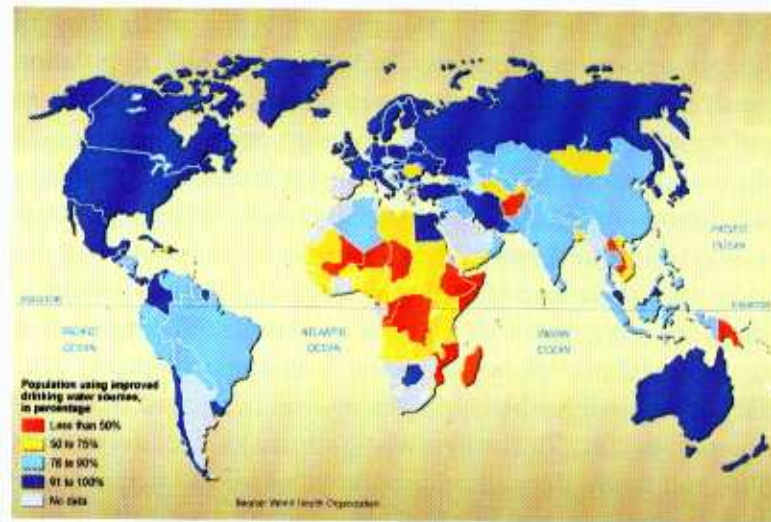
an uneven geographical and seasonal distribution of rainfall. River flows are highly variable. Australia has one of the world's largest aquifer systems, the Great Artesian Basin estimated at 1.7 million km² and a storage volume of 8.7 km³.

Global Groundwater Situation

Throughout the world, groundwater balance is shrinking day by day. Groundwater is also critical in supplying the industrial water demand in most countries. In some of the most populous and poverty-stricken regions of the world—particularly in South Asia—groundwater has emerged at the center-stage of the food-agricultural economy. In regions with high population density, dynamic tube-well-irrigated agriculture, insufficient surface water, and inadequate drainage, many consequences of groundwater problems are becoming increasingly evident. The most daunting challenges that the world faces in the water sector are decline in water tables due to overdraft; waterlogging and salinization; and pollution due to agricultural, industrial and other human activities. The estimates of 1997 suggest that the groundwater use for the world as a whole is around 750–800 km³ annually, which appears modest compared to overall water availability. But an overwhelming majority of the world's cities and towns depend on groundwater for municipal water supplies.

Half of the US population draws its domestic water supply from groundwater. During 1990s, India, China, the US and Pakistan together used about 325 km³ of groundwater every year; and over 35 countries of the world used more than 1 km³ of groundwater annually. In comparison, world's aggregate groundwater resources appear abundant. Groundwater, both stock and flow, constitutes over two-third of the world's freshwater resource, if we exclude glaciers and permanent snow cover. Even if 8% of the 33,000 km³ floodwater that runs

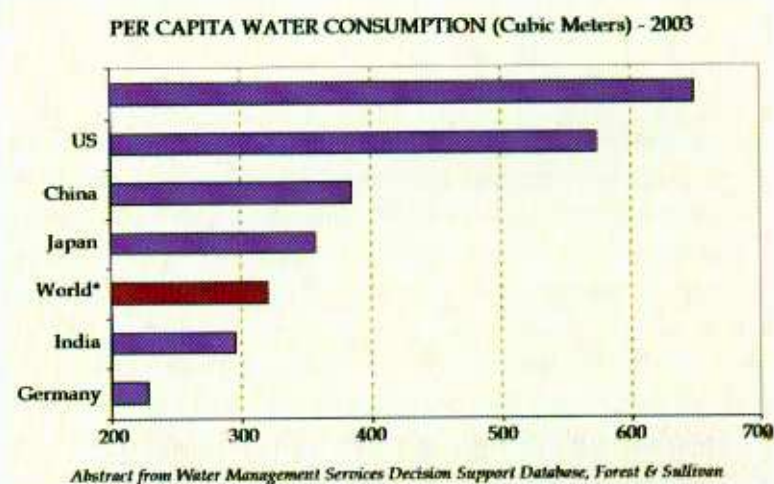
off to the oceans annually recharge the groundwater, we have a renewable supply of over 2,500 km³ of groundwater annually, which seems several times more than the world uses. According to FAO's AQUASTAT, the Russian Federation uses less than 5% of its 900 km³ of annual recharge; West Africa uses less than 1%; China's renewable groundwater supply is estimated at over 800 km³; but it uses just around 70%; even India, which has serious overexploitation problems uses only 33% of the estimated annual recharge of some 450 km³.



Population (in percentage) using improved drinking water sources.

Urban industrialization is also a major contributor to urban groundwater problems. In the Fuyang river basin of North China the water table has fallen from 8 to 50 meters during 1967–2000 and industries are polluting the upper zones; in South Korea's industrial cities such as Seoul, Pusan and Daegu, water tables have dropped by 10–50 meters over a 30-year period due to industrial pumping. In the Cheju island, seawater intrusion in coastal aquifer has been the direct result of industrial pumping of groundwater. Mexico's aquifers too

are amongst the most overdeveloped; Guanajuato State, one of Mexico's agriculturally dynamic regions, water tables in 10 aquifers are declining at average annual rates of 1.79–3.3 meters/year during recent years. Groundwater problems in West and South Asia are as pernicious as or even worse than those in China. Bangkok, Jakarta and Mexico city have been facing acute problems of land subsidence because of groundwater depletion. Aquifer pollution—from both point and nonpoint sources—is becoming extensive worldwide. In the Gediz basin of Anatolia, Turkey, nonpoint pollutants—



Source: www.growthconsulting.frost.com/web/images.nsf...
(Accessed on 16.10.2006)

mostly agrochemicals—have polluted the groundwater and the river downstream. One of the most serious ill effects of depletion is from seawater intrusion in coastal aquifers as in Egypt, Turkey, China and India.

Access to an improved drinking water source: Increased from 77% of the population in 1990 to 83% in 2002. Despite this progress, still over one billion people have yet to benefit,

with coverage in rural areas lagging seriously behind that in urban areas, with 95% of the urban population having access to improved water sources in 2002 compared to 72% of the rural population. Inadequate water supply and sanitation affects multiple dimensions of poverty, including health, education and degradation of the environment. In 2002, about 3,900 children under five died each day because of diarrhea attributed to unsafe water supplies and poor sanitation and hygiene. Access to an improved water source would be an important step toward improving health outcomes.



Indian Scenario

India, with a total area of 3,287,263 Km², is endowed with abundant water in the perennial resources of Himalayan glaciers, the water generated by monsoons, the groundwater resources and a long coastline. Yet, the actual distribution over space and time is strongly influenced by a number of climatic and geographic factors, and freshwater crisis exists in many parts at different times of a year. Two-third of available freshwater is lost due to evaporation and runoff into the Sea. Over the years, the annual per capita availability of renewable freshwater has shrunk alarmingly, to meet the demands of different sectors. From around 5,277 cubic metres in 1955 it dipped to below 1,820 cubic metres in 2001. India is the second largest water consuming country in the world, after China, and per capita water consumption is less than the world average by 7.6%. The domestic sector demand accounts for only 5% of the annual freshwater withdrawals, and over the next twenty years is likely to increase from 25 billion m³ to 52 billion m³. With increasing population and depleting water resources, the per capita water consumption in India is expected to decrease at a compound annual growth rate of approximately 1%, during the period 2003-2006. With increase in industrial production,

water consumption for this sector has grown and will continue to grow at a rate of 4.2% per year. According to the World Bank, demand of water for industrial, energy production and other uses will rise from 67 billion m³ to 228 billion m³ by 2025.

Agriculture remains central to the Indian economy and is heavily dependent on irrigation. Due to a large annual regional and seasonal variation in rainfall, agriculture receives a greater share of the annual water allocation. Water demand for agriculture in 1990 was 46 mhm, and is likely to go up to 77 mhm by 2025. Irrigation accounts for over 95% of freshwater withdrawals consumed in several States and roughly 80% nationwide. India has the largest irrigation infrastructure in the world, but the irrigation efficiencies are low, at around 35%. By the yardstick of irrigation efficiency and not by the net area irrigated, doubtless, groundwater is the most important resource. Groundwater alone accounts for 39% of the water used in agriculture and surface water use often comes at the expense of other sectors such as the industrial and domestic supply. Over 80% of the rural domestic water comes from groundwater sources. This dependence on groundwater is particularly critical where dry season surface water levels are low.

200 million people do not have access to clean drinking water. Currently, only 85% of the urban and 79% of the rural population has access to safe drinking water and fewer still have access to adequate sanitation facilities. Although, most urban areas in India are serviced by a municipal water supply system, usually originating from local reservoirs or canals, or imported through inter-basin transfer, these schemes often do not adequately cover the entire urban population and are inefficient and unreliable with zonal disparity. Since colonial times and after independence, these systems did not receive as much attention as desirable, in favor of large dam and canal

irrigation projects, which could provide water to selected parts of India. Yet, high economic, social and environmental costs have not provided their overall benefit. Still, in rural areas where water is scarce, women have to travel long distances to wells or streams to fetch water.

Physiography: India can be divided into well-defined regions: (i) The Northern Mountains, comprising the mighty Himalayan ranges; (ii) the Great Plains, traversed by the Indus and Ganga-Brahmaputra river systems; (iii) the Central Highlands, consisting of the Aravalli ranges in the west and terminating in a steep escarpment in the east. The area lies between the Great Plains and the Deccan Plateau; (iv) the Peninsular Plateaus comprising the Western Ghats, Eastern Ghats, North Deccan Plateau, South Deccan Plateau and Eastern Plateau; (v) the East Coast, a belt of land of about 100-130 km wide, bordering the Bay of Bengal land lying to the east of the Eastern Ghats; (vi) the West Coast, a narrow belt of land of about 10-25 km wide, bordering the Arabian Sea and lying to the west of the Western Ghats, and (vii) the islands, comprising the coral islands of Lakshadweep in Arabian Sea and Andaman and Nicobar Islands of the Bay of Bengal.

Climate: The great mountain mass, formed by the Himalayas and its spurs on the North and the ocean on the South are the two major influences governing the climate. The first acts as an impenetrable barrier to the influence of cold winds from central Asia and gives the sub-continent a tropical type of climate. The second is the source of cool moisture-laden winds giving it the oceanic type of climate. The Indian climate ranges from continental to oceanic, from extremes of heat to extremes of cold, from extreme aridity and negligible rainfall to excessive humidity and torrential rainfall. The climatic condition influences to a great extent the water resources utilization of the country.

Water Resources Availability	
(In Billion Cubic Metre)	
Total Precipitation	: 4000
Total Water Availability	: 1869
Total Utilisable Water	: 1122 (690 SW + 432 GW)
India's Water Resources	: 4% of Global Water Resources

Rainfall: The main source of water in the country - annual rainfall including snowfall, is adequate and estimated to be of the order of 4000 cu.km (400 mhm), 75% occurs just in the four months June to September of the monsoon period and 50% falling in just 15 days. With an average annual rainfall of 1,170 mm, India is one of the wettest countries in the world. However, there are large variations in the seasonal and geographical distribution of rainfall over the country. At one extreme are areas like Cherrapunji, in the northeast, which receives each year with 11,000 mm rainfall, and at the other extreme are places like Jaisalmer, in the west, which receives barely 100-200 mm of annual rainfall. Though the rainfall over India is slightly above global average, its erratic and uneven distribution leads to occasional floods and droughts, in different parts. Only 28% of annual rainfall is available for utilization; 70 m ha m surface water and 42 mhm groundwater. The amount of water that can be actually put to beneficial use is much less due to the constraints in the technology for storing water and inter-state issues. The storage capacity of all the surface water storage reservoirs/tanks, existing, under construction and contemplated, add up to 40 mhm, which is only about 60% of the utilizable surface water potential and meager 3% of the average annual rainfall.

Surface Water Resources: India is endowed with many rivers. There are 15 major basin (drainage area >20,000 km²),

Rainfall Distribution in India

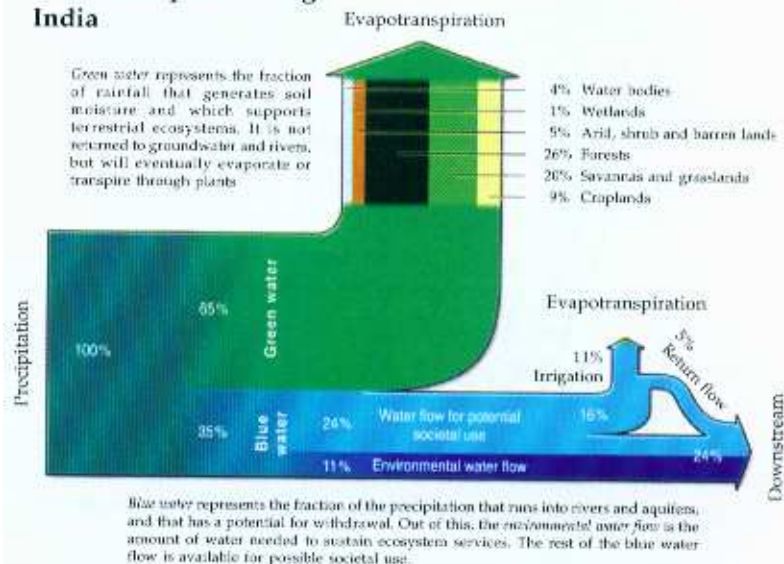


(Source: India Meteorological Department; www.imd.ernet.in/.../jun-sep-rainfall.htm)

45 medium (2,000 to 20,000 km²) and over 120 minor (<2,000 km²) rivers, besides numerous ephemeral streams in the western arid region. Over 90% of river flows occur in just four months. For large-scale analysis of water-resources, the country is often separated into 19 major river basins that constitute about 83-84% of the total drainage area. This, along with the medium river basins, accounts for 91% of the total drainage. 12 are classified as major rivers, whose total catchment area is 252.8 million hectare (m.ha). Of the major rivers, the Ganga-Brahmaputra-Meghana system is the biggest with a catchment

area of about 110 m.ha, which is more than 43% of the catchment area of all the major rivers. The other major rivers with catchment area of more than 10 m.ha are the Indus (32.1 m.ha.), the Godavari (31.3 m.ha.), Krishna, (25.9 m.ha.) and the Mahanadi (14.2 m.ha.). The catchment area of medium rivers is about 25 m.ha and the Subarnarekha with 1.9 m.ha. catchment area is the largest among the medium rivers in the

Rainwater partitioning: India

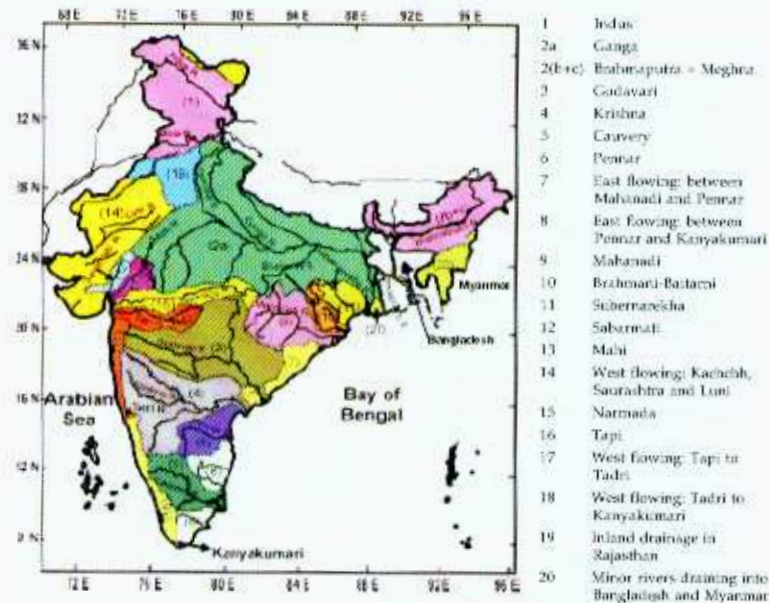


Source: Stockholm Environment Institute. Sustainable Pathways to Attain the Millennium Development Goals Assessing the Key Role of Water, Energy and Sanitation. 2005.

country. The average flood discharge of Ganga is 50,000 cubic meter per second and that for the Brahmaputra is 60,000 cubic meter per second.

The resource potential of the country, which occurs as a natural run-off in the rivers, is about 1869 km³/year, (as per the basin-wise latest estimates of the Central Water Commission) including regenerating flow from groundwater and the flow from neighbouring countries, considering both

Major River Drainage Basins in India



(Source: Gupta and Deshpande, 2004).

surface and ground water as one system. Of which only 690 km^3 are considered as utilizable in view of the constraints of the present technology for water storage and inter-state issues. A significant part ($647.2 \text{ km}^3/\text{year}$) of these estimated water resources come from neighbouring countries: $210.2 \text{ km}^3/\text{year}$ from Nepal, $347 \text{ km}^3/\text{year}$ from China (Chinese data) and $90 \text{ km}^3/\text{year}$ from Bhutan. An important part of the surface water resources leaves the country before it reaches the sea: $20 \text{ km}^3/\text{year}$ to Myanmar, $181.37 \text{ km}^3/\text{year}$ to Pakistan (Pakistani information) and $1105.6 \text{ km}^3/\text{year}$ to Bangladesh. The Central Water Commission estimates the groundwater resources at $418.5 \text{ km}^3/\text{year}$. Part of this amount, estimated at $380 \text{ km}^3/\text{year}$, constitutes the base flow of the rivers. The total renewable water resources of India are therefore estimated at $1907.8 \text{ km}^3/\text{year}$.

The availability of water resources in various river basins of the country is highly uneven. The utilizable water resource has been assessed as 1,132 BCM. The Ganga-Brahmaputra-Meghna system, covering only 33% of the area is the major contributor to water resource, accounting for about 60% in the total potential of the various rivers and about 40% of utilisable surface water resources. In a majority of river basins, the present utilisation is significantly high and is in the range of 50-95% of utilisable surface resources. But in rivers such as the Narmada and Mahanadi, the percentage utilisation is quite low, 23% and 34% respectively. While 32% of the total water resources are still available in the Brahmaputra basin, and 28% of the total water resources in the Ganga basin, this availability is merely 0.2% in the Sabarmati basin. Catchments of the western coast rivers occupy only 3% of the land area, and account for 11% of the water resources. Thus 71% of water resources are available to only 36% of the area and the rest 64% of area has to do with remaining 29% of the water resources.

The inland water resources of the country are classified as rivers and canals; reservoirs; tanks and ponds; beels, oxbow lakes, derelict water; and brackish water. The total area of inland water resources is unevenly distributed over the country with Orissa, Andhra Pradesh, Gujarat, Karnataka and West Bengal accounting for more than 50% of the inland water bodies. Other than rivers and canals, the total water bodies cover about 7 m.ha. Of the rivers and canals, Uttar Pradesh occupies the first place with a total length of rivers and canals as 31.2 thousand km, which is about 17% of the total length of rivers and canals. The other States following Uttar Pradesh are Jammu & Kashmir and Madhya Pradesh. Among the remaining forms of the inland water resources, tanks and ponds have a maximum area (2.9 m.ha.) followed by reservoirs (2.1 m.ha.). The States of Andhra Pradesh, Karnataka and Tamil Nadu, West Bengal, Rajasthan and Uttar Pradesh, account for

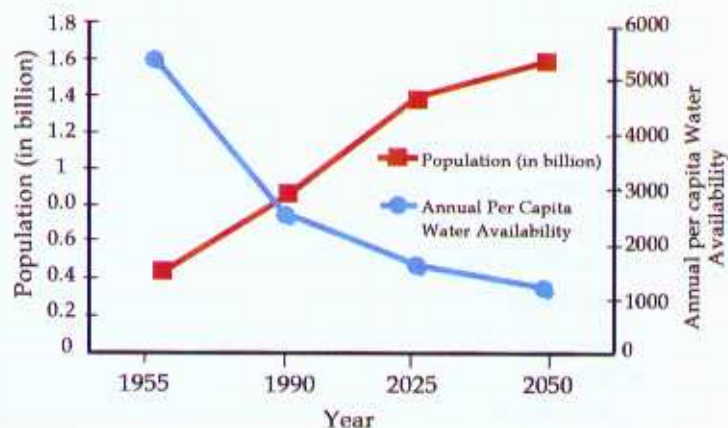
62% of the total area under tanks and ponds in the country. As far as the reservoirs are concerned, major States like Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Rajasthan and Uttar Pradesh account for a large portion of the area. More than 77% of area under beels, oxbow lakes and derelict water lies in the States of Orissa, Uttar Pradesh and Assam. Orissa ranks first as regards the total area of brackish water and is followed by Gujarat, Kerala and West Bengal.

The distribution of water resource potential in the country shows that as against the national per capita annual availability of water at 2208 cu.m., the average availability in the Brahmaputra and the Barak rivers is as high as 16589 cu.m. while it is as low as 360 cu.m. in the Sabarmati basin. The Brahmaputra and the Barak basin with 7.3% of geographical area and 4.2% of population of the country have 31% of the annual water resources. Per capita annual availability for the rest of the country excluding the Brahmaputra and Barak basin works out to about 1583 cu.m. Any situation of availability of less than 1000 cu.m. per capita is considered by international agencies as a scarcity condition. Out of 12 major and 48 medium river basins in India, the government predicts that by 2025 the deficit river basins will be Ganga, Subernarekha, Krishna, Mahi, Tapi, Cauvery, Pennar and Sabarmati. The surplus basins would be Brhamaputra, Barak, Narmada, Brahmani-Baitarani, Mahanadi, Godavari and Indus.

Renewable water resources of India are about 4% of the global availability. In India, annual average per capita fresh water availability dropped from 5,177 cu.m. in 1951 to 1,820 cu.m. in 2001. It is predicted that by 2025, per capita annual average fresh water availability will be 1,340 cubic metre approximately. Already, the potential of most river basins is being exploited beyond 50% and several basins are considered

to be water scarce. About 200 million Indians do not have access to safe and clean water. An estimated 90% of the country's water resources are polluted with untreated industrial and domestic waste, pesticides, and fertilizers. According to the United Nations Environment Programme, India will be 'water-stressed' before 2005 (a country is considered 'water-stressed' if its water availability is between 1000 to 1700 cubic metres per person). While rural water demand is assessed on an allocation of 40 litres per capita per day (lpcd), the corresponding urban demand is against a norm of 135 lpcd.

Population and water availability trends in India



Note : Government projections; increasing sectoral demands planned to be met through new construction

Source: Population Action International 1995; World Bank, 1977a

If the accepted level of allocation (135 lpcd) is to be sustained in the year 2050, each of the metros will have to search for fresh sources of water to meet the growing demand. Water tariffs have remained lowest in the country's urban centres. In

Delhi, Mumbai and Chennai, water is supplied at Rs 0.5, 1.6 and 2.7 per cubic metre respectively. This means that the rich pay a fraction (less than 10%) of the actual cost of producing potable water. Such low tariffs can only encourage wasteful water utilisation.

Trends in ground-water use, 1950-2000

Ground water is a valuable resource in India, and is vitally important in supplying water for everyday water needs. India's groundwater resources are almost ten times its annual rainfall. According to the Central Ground Water Board of the Government of India, the country has an annual exploitable groundwater potential of 26.5 million hectare-meters. Over 80% of the domestic water supply in India is dependent on groundwater. However, groundwater is fast depleting. Water tables have fallen significantly in most areas at the rate of one to three meters every year and there is a significant pollution of groundwater from natural as well as manmade sources. Nearly 85% of currently exploited groundwater is used only for irrigation. Groundwater accounts for as much as 70-80% of the value of farm produce attributable to irrigation. Besides, groundwater is now the source of four-fifths of the domestic water supply in rural areas, and around half that of urban and industrial areas. Furthermore, the estimates suggest that India is using its underground water resources at least twice as fast they are being replenished. Already, excessive ground water mining has caused land subsidence in several regions of Central Uttar Pradesh.

Ground water is used to irrigate crops and supply homes, businesses, and industries with water, where surface water sources are scarce or inaccessible. The majority of ground water goes towards crop irrigation, with the next largest use being

Water quality in major river systems of India



Class A: Water fit for drinking after proper disinfection.

Class B: Water is fit for bathing.

Class C: Water fit for drinking only after proper treatment

Class D: Water fit for fish and wildlife.

Class E: Suitable only for industrial cooling, irrigation, etc.

Source: www.edugreen.teri.res.in/explore/maps/water.htm
 (accessed on 24th Oct, 2006)

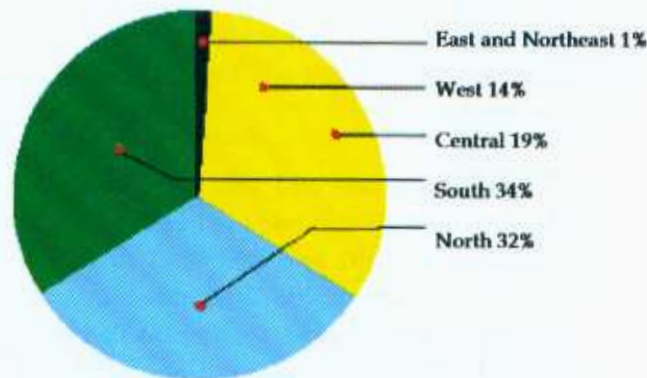
water withdrawn for public-supply purposes, and it provides over 50 billion gallons per day for agricultural needs. It is the source of drinking water for about half the total population and nearly all of the rural population. Groundwater development is about 106% in Delhi, 94% in Punjab, 84% in Haryana, 60% in Uttar Pradesh, 41-51% in the western states, 17-30% in the central states, and 24-60% in the southern states (CGWB, 1998). Against a critical level of 85%, there are blocks in Gujarat, Punjab, Haryana and Rajasthan, where over-abstraction is 100-260%. Many areas of India are experiencing ground-water depletion, a term often defined as long-term water-level declines caused by excessive ground-water pumping, which is a key issue associated with ground-water use.

Extensive urbanization and land use changes in many parts of India have caused compaction of the top sub-soil and significant shrinking of the exposed land surface to direct infiltration of rainfall (Datta, 2000). Groundwater recharge from rainfall varies widely from region to region and within the parts of a region, depending on the frequency, intensity and distribution of rainfall, evaporation, soil clay content and landuse. In Delhi area, contemporary recharge is very limited and ranges from <5-30%, with most parts receiving <5% recharge (Datta et al, 2001). The average recharge from rainfall has been reported to be 18% in Punjab, 15% in Haryana, 20% in western Uttar Pradesh, 1-14% in Rajasthan, 8-14% in Gujarat, 11% in the alluvial deposits of Maharashtra, and 8% in Andhra Pradesh, (Datta, 2000). A comparison of the results for the Sabarmati basin with those of the Ganga, the Ramganga and the Yamuna basins in the Indo-Gangetic Plains indicated a relatively higher efficiency of winter rains in inducing groundwater recharge [Datta et al, 1979]. Higher potential evaporation during monsoon months in Sabarmati basin may be expected to reduce the net groundwater recharge for a certain amount of water input [Datta et al, 1980a]. The radiocarbon

concentrations of confined groundwaters in Gujarat and Rajasthan indicated significant amounts of fresh water recharge even in areas far away from the principal recharge areas of aquifers [Borole et al, 1979].

The volume and level of ground water is decreasing in many areas of the country due to excessive pumping at a faster

Groundwater over-development in India by region



Unbalanced groundwater recharge and lowering of the water table: Some examples

rate than it can be recharged. Over the last three decades, the rapid expansion in the use of groundwater primarily for irrigation has contributed significantly to agricultural and economic development in India. Groundwater irrigation potential, the number of wells and the number of energized pump sets have grown exponentially since the early 1950s. With more than 17 million wells nationwide, groundwater now supplies more than 50 percent of the irrigated area and, due to higher yields in groundwater irrigated areas; it is essential for an even higher proportion of the total irrigated output. The practice of sale of water, either on cash or on crop sharing basis has also encouraged rich farmers constructing deep tubewells

and over-pumping the groundwater. According to some estimates, 70-80 percent of the value of irrigated production in India may depend on groundwater irrigation. Current projections suggest that the rapid rate of development will continue until the full irrigation potential estimated to be available from groundwater is reached in about 2007.

In highly urbanized areas, such as Delhi area, annual recharge being very small, as compared to the groundwater withdrawal, water table declined by 2-8 m in different parts during the last decade and 2-20 m during 1960-2000 (Datta et al, 2001; Rohilla et al, 1999). In the past two decades, water table in 77% area of the Punjab State, with exploitation as high as 98%, has fallen by 25-30 cm a year and is now stationed at 50-60 m. Increase in cropping intensity and replacement of less water consuming crops with more water requiring crops yielding better economic return has resulted in more water demand (Datta, 2000; CGWB, 1998). During the last decade, groundwater table declined by 0.2-3.0 m in Uttar Pradesh, 3-8 m in Haryana, and 7-10 m in Rajasthan. In different blocks of the north-western Uttar Pradesh, during 1977-1996, water table declined from 1m to 10 m. In Gujarat, decline in the groundwater table increased from 1m y^{-1} in 1970 to $2-8\text{m y}^{-1}$ in 1997 (CGWB, 1998). The water table in the Thar Desert, Gujarat and parts of peninsular India has sunk by 20-60 metres in the past 35 years. In Jalgaon district of Maharashtra State, during 1981-1996, water table declined by 13.30 m. Considerable decline ($>4\text{ m}$) in groundwater table, during 1988-1998, has been observed in other States also. If ground-water levels decline too far, then the well owner might have to deepen the well, drill a new well, or, at least, attempt to lower the pump. Also, as water levels decline, the water yield may decrease, more energy is required to lift upto the land surface. Using the well can become prohibitively expensive.

Deterioration of water quality: some case studies

The country is facing a water quality crisis. Water pollution is a serious problem surface water resource and biological, toxic organic and inorganic pollutants already contaminate a growing number of groundwater reserves. With so many avenues for its contamination, being a universal solvent, water tends to dissolve anything and everything that comes its way, thus changing its quality every minute. One water-quality threat to fresh ground-water supplies is contamination from saltwater intrusion. Under natural conditions the boundary between the freshwater and saltwater tends to be relatively stable, but pumping can cause saltwater to migrate inland and upward, resulting in saltwater contamination of the water supply. Due to public ignorance to environmental considerations and lack of provisional basic social services, indiscriminate disposal of increasing anthropogenic wastes on land, into river and unlined drains, and unplanned application of agro-chemicals and improperly treated sewage water continued, resulting in excessive accumulation of pollutants on the land surface. Sub-surface leaching of contaminants from landfills as well as seepage from canals/river and drains caused severe degradation of the groundwater, at many places, exceeding the WHO prescribed maximum permissible limits in drinking water.

The groundwater in different parts of Delhi has become considerably vulnerable to pollution with a wide range of contaminants. Large part of Delhi area is severely affected by fluoride ($<1\text{--}16.0\text{ mg l}^{-1}$) and nitrate ($<20\text{--}1600\text{ mg l}^{-1}$) pollution of groundwater (Datta et al, 1996a, 1997). Fluoride and nitrate levels increased by 2-6 times, during the last decade. In Punjab, Haryana, Gujarat, Maharashtra and Karnataka, groundwater nitrate level ranges from $<25\text{ mg l}^{-1}$ to 1800 mg l^{-1} , and fluoride level $1.5\text{--}45.8\text{ mg l}^{-1}$. High concentration of fluoride ($1.5\text{--}45.8$

mg l⁻¹) has been reported from different parts in the other states also. Highly skewed distribution and wide range of fluoride and nitrate suggest contamination from both point and non-point sources. In the absence of known major geological source of fluoride and nitrate in the NCR, excessive application of fertilizers and discharges from steel, aluminum, brick and tile industries, barn yard and silo wastes, and disposal of crop residues are major causes of pollution.

In West Bengal, the consequences of arsenic contamination are evident. Trace to excessive amounts of heavy metals, such as, Zn (3-41 µg/l), Cu (5-182 µg/l), Fe (279-1067 µg/l), Mn (<1-76 µg/l), Pb (31-622 µg/l), Ni (<1-105 µg/l), Cd (<1-202 µg/l) is found mostly in the groundwaters at some places of Delhi near industrial sites (Datta et al, 1999), Haryana, Uttar Pradesh, Andhra Pradesh and Madhya Pradesh. Slow infiltration of agricultural and urban surface run-off, carrying alongwith pollutants present in agro-chemicals and wastes generated by human activities, causes contamination (Datta et al, 1996a, 1997)). Adsorption/dispersion processes in the soil zone, degrees of evaporation/recharge and lateral inter-mixing of groundwater determine the level of contaminants in groundwater. Over-exploitation induced changes in hydraulic head cause intermixing of contaminated groundwater with fresh water along specific flow-pathways (Datta et al, 1996), increasing lateral extension of contaminated groundwater and decrease in the available fresh water potential. Obviously, limit of vulnerability to depletion has reached.

Water Demand and Consumption Patterns

Indians consume 470 cubic meters of water per person per year; Chinese consume 407 cubic meters water per person per year. In China, one dollar of GNP is produced per every 370 liters of water; in India 880 liters of water are required. In the USA, water consumption at 1,606 cubic meters per person per year,

Present and Future Water Demand				
Sector	Water Demand in BCM			
Year	2050	2025	2010	2000
Irrigation	1072	910	6885	41
Domestic	102	73	56	42
Industry	63	23	12	8
Energy	130	15	5	2
Others	80	72	52	41
Total	1447	1093	813	634

(Source: Standing Sub-committee on assessment of availability and requirement of water)

Ministry/Institution	Portfolio
• Ministry of Water Resources	Principal agency responsible for all water in the country
• Ministry of Rural Development	Watershed development and water supply in rural areas
• Ministry of Urban Development	Drinking water supply in urban areas
• Ministry of Power	Development of Mega hydroelectric projects
• Ministry of Non-Conventional Energy Sources	Development of micro and mini hydel potential.
• Ministry of Environment and Forests	Quality of surface and groundwater
• Ministry of Agriculture	Providing resources for irrigation of agricultural lands
• Ministry of Industry	Planning and development of water for industry
• Central Pollution Control Board	Monitoring and regulation of industrial water pollution
• Central Ground Water Authority	Regulation of quantity and quality of groundwater
• Water Quality Assessment Authority	Apex body set up by MoWR and MoEF, yet to start effective functioning

a dollar of GNP requires only four liters of water. In the more water-frugal European Community, where each person consumes 605 cubic meters of water per year, a dollar of GNP requires a mere three liters of water. A region where renewable fresh water availability is below 1700 cubic meters/capita/annum is a 'water stress' region, and one where availability falls below 1000 cubic meters/capita/annum experiences chronic 'water scarcity'. The annual per capita availability of

Water Resources: Country profile - India		
Internal Renewable Water Resources(1977-2001, in cubic km)		
	India	Asia (excl. Middle East)
Surface water produced internally	1222	10985
Groundwater Recharge	419	2472
Overlap (shared by Groundwater and surface water)	380	2136
Total Internal Renewable Water Resources (surface water + groundwater - overlap)	1261	11321
Per capita IRWR, 2001 (cubic meters)	1211	3241
Total, 1977-2001 (cubic km)	1897	X
Per capita, 2002 (cubic meters per person)	1822	X
From other countries (cubic km)	647	X
To other countries (cubic km)	1307	X
Year of Withdrawal Data	1990	
Total withdrawals (cubic km)	500	X
Withdrawals per capita (cubic m)	592	X
Renewable Water Resources	32.5 %	X
Agriculture	92 %	X
Industry	3 %	X
Domestic	5 %	X

renewable freshwater in India has fallen from around 5,277 cubic meters in 1955 to 2,464 cubic meters in 1990. Given the projected increase in population by the year 2025, the per capita availability is likely to drop to below 1,000 cubic meters i.e., to levels of water scarcity. If per capita water availability is any indication, 'water stress' has just begun to show in India.

As per the estimation of the National Commission for Integrated Water Resources Development, the demand in 2010, 2025 and 2050 is likely to be 710, 843 and 1180 BCM respectively, assuming gradually increase in irrigation efficiency to 60% from 35-40% at present. Though water is constitutionally a state subject, Government policies, multiplicities of activities and economic incentives have also influenced the water distribution and consumption across India. While the Constitution mandates panchayats to control and manage water at the local level, water remains under the control of a number of ministries and institutions.



Future Scope

Functions of any area are generally linked to short-term and long-term land use changes and have consequences on the water resource. It has been difficult to accurately assess world water resources and their response to the important factors of global change, namely: climatic variability; land cover change, industrialization and population growth; and the control of the natural water cycle through hydraulic engineering. Carefully maintained and reliable records of global hydrologic change to judge the cumulative impact of human activities on the world freshwater systems are not available. For example, the public usually has neither any notion about groundwater quantity nor have any infrastructure to assess its quality at hand. The common man judges its availability for general purposes in terms of the depth to groundwater below the surface and quality in terms of color, odor and taste; and thus determines their land use characteristics. Their demands on land and groundwater and the consequences of these demands have been characterized scarcely. To manage with the situation, an ad hoc and tactical approach has been taken. The regulation of groundwater exploitation is mainly achieved through control of borehole

drilling or licensing their pumping. Due to absence of any pricing mechanism and strict regulation, indiscriminate groundwater exploitation, its wasteful utilization, and land disposal of wastes continued.

Most of the hydro-geological and groundwater development/protection research has been largely fragmented, technocratic and relates to groundwater flow and remediation. The research related to groundwater use in the social and economic context being relatively small, the research on its own is of relatively little use for practical management purposes. Despite the highly technical work presented in the literature, the status of knowledge of the aquifer systems is often limited at the level at which a management response is required. With deterioration in routine monitoring networks in many parts of the world, for all practical purposes, an accurate assessment is extremely difficult. There is a need for detailed studies of complex drainage basins that collectively represent the domain over which anthropogenic change and its impact on water resources and the sustainability of the biosphere can be reasonably assessed.

To optimize the water-use in the long term, and to protect and conserve it as required, some of the important aspects with which water resources managers are confronted, include characteristics of river water flow, discharges, groundwater renewal, flow velocity and direction, its interaction with each other as well as with surface water bodies, the sources of pollution, trace the movement of pollutants and containment of spreading from known sources, quality of water and causes of quality deterioration. These parameters must be measured under both the steady and non-steady conditions. Efficient irrigation systems and

water management practices can help reduce the impact of irrigated production on offsite water quantity and quality. Producers may reduce water use by applying less than full crop-consumptive requirements, shifting to alternative crops or varieties of the same crop that use less water, or adopting more efficient irrigation technologies. In some cases, the effectiveness of improved practices such as irrigation scheduling and water-flow measurement may be enhanced in combination with other farming practices such as conservation tillage and nutrient management.

This calls for a thorough scientific knowledge and precise understanding of the key interaction processes of the system with the biophysical and hydrological environment, in different regions and within the parts of a region. Generally, studies on regional flow systems adopted a hydraulic approach, based on gravity-induced flow from high to low head. However, the usual method of water level distribution analyses provides a short-term feature of the hydraulics. Modeling can be used to study impacts and trends resulting from various development options, addressing and simulating not only economic efficiency and technical merits, but also the preferences and priorities of stakeholders. Nonetheless, several opportunities exist for analyzing the global status of the land phase of the hydrological cycle and associated water resources. Scope exists therefore to “upscale” local-scale knowledge to estimate and to develop the hydrological and water management strategies for ecological, social and economic sustainability over larger domains. The basin scale is appropriate for comparing water resources (precipitation, groundwater, surface water) and water use or water demand (domestic, industrial, agricultural). However, the mechanisms that govern water demand are not well outlined and relevant parameters are yet to be suggested.

There remains much to do in order to obtain sound statistics on water resources, and particularly standardized data sets, at global level. Therefore, the methodology used to compute water resources is intentionally simple and based on transparent rules. More effort needs to be focused on the assessment of the variability of water resources in space (watershed level), in time (dry-year resources) and according to constraints (exploitable resources). National averages hide local differences and, for large countries, are of little use for assessing the country's water situation. The use of global data sets (meteorological, etc.) coupled with water-balance models can contribute to improving the assessment of water resources. The emergence of improved models, high quality isotopic and biophysical data, remote sensing imagery, information technology, higher level of computational capability, and data assimilation schemes, provide a unique opportunity to monitor the state of the hydrological cycle over broad domains and in near-real time, with a much higher spatial and temporal resolution. In India, isotope techniques and remote sensing have been used extensively, for over three decades, to understand the water cycle, surface water status, soil water movement, groundwater flow regime, recharge and contamination characteristics, residence time (age) in the aquifer, groundwater-surface water interactions, groundwater hydrodynamic zones, flow-pathways and mixing processes in groundwater system.

Emphasis is now being given also to the nature of water as an economic resource in global debates. Yet, water tariffs in many areas are very low for public supply and there is no mechanism of pricing for extraction of groundwater. The level of subsidy is extremely high for domestic consumption. Majority thinks water is available free of cost. This leads to more consumption and wasteful utilisation, resulting in low

level of revenue collection. This falls far short of covering the cost of production and hinders the investment capacities of the public utility. The massive investments required to avoid pollution, remediate polluted aquifers and control overdraft prompted the planners, developers and managers to think of the estimates of the value of groundwater.

With an extremely uneven natural space-and-time water resources distribution, an intensive man's activities, and a rapid population growth, even at the present time a significant fresh water deficit exists in many countries and regions, especially during dry years. In the decades to come, the most of Earth's population and many countries in the world would have a critical situation with water supply. Water resources deficit becomes a factor deteriorating the living standard of population retarding the economic and social development in most developing countries of the world. It is already clear that in the first half of the 21st century the water problem will be of the most importance even among such global problems of humankind as food and power production. Scope exists to cover all levels and aspects of education, information transfer and training, a clear priority is to be given to higher education, including institutional capacity building and networking, education for research at postgraduate level, continuing professional education and to activities targeting "training of trainers", within the domain of education and training.

The central issue is re-defining water governance. To improve the situation alternative institutional arrangements have to be examined along with the effective control of the existing institutions. In the context of groundwater, there is a need to develop management principles addressing ecological, equity and sustainability concerns. It is also desirable to identify, strengthen and provide legal validity to

local institutions, which can ensure equitable and sustainable use of water, within ecological confines. In addition to the institutional reforms; differential water pricing and water conservation at all levels are the issues of paramount importance that must be addressed in order to tide over the present scarcity and the emerging threat of conflicts over water.



Activity

The river runoff resources as a whole on the Earth are sufficient enough to meet the demands for water requirements for many decades ahead. The competition for economic developments increases the unevenness in spatial distribution of water resources. Therefore, the human intention is obvious to work out and implement the measures for water intake from those regions, where it is in excess, and water transfer to the regions with its insufficiency. At present and in the near future, the most realistic and efficient measures would be: (i) overall economy and protection of water resources by a drastic decrease in specific water consumption, especially in irrigated landuse and industry; (ii) reduction or full cessation of waste water discharge into the hydrological system; (iii) more efficient use of local waters as a result of seasonal and long-term river runoff regulation; (iv) use of salt and brackish waters; (v) an active influence on precipitation-forming processes; (vi) use of secular water storage in lakes, underground aquifers, glaciers; and (vii) the territorial re-distribution of water resources. All these measures require rather great material expenses and have different limitations.

The management options of groundwater in urban areas are generally based on the patterns of groundwater use, and the responsibility remains largely with municipal supply utilities, as well as with individuals. While, rural users generally abstract groundwater themselves through wells that they own and control. There has been relatively little research on groundwater availability in hard-rock regions in India, because they typically form poor aquifers. Human activities induced consequences, such as, groundwater over-exploitation and its decline, are linked with non-availability of adequate water and its distribution, increase in population density and socio-economic development, public attitude and perception towards environmental issues. Associated with these, the amount of waste generated, changes in settlement pattern and land use determine groundwater contamination. The aggregate impact of millions of individual pumping decisions, and of emerging groundwater problems, the hydrogeological, social, economic, cultural and political factors can vary greatly at local or regional scales, and no single template for management can be developed.

The two generally acceptable approaches are: (i) Optimal yield, which allows for the deliberate short-term controlled use of storage between recharge events, and (ii) Controlled over exploitation, which recognise that some permanent depletion in storage may be necessary to promote socio-economic development where recharge is very limited, whilst for example, water conservation measures are introduced. For practical management practices it is important to examine: (i) people's adaptive strategies, such as, water harvesting, alternative livelihoods and demographic shifts, when they face with groundwater scarcity problems; and (ii) the policy implications, like drought relief, climate-change response, investment directions, institutional forms, etc.. However, no

comprehensive analysis with specific application to groundwater is available so far.

There is a need for detailed basic research programme to gather data, covering all key elements of the hydrological cycle in order to develop an improved picture of water use and conditions. For comprehensive evaluation of the groundwater vulnerability, groundwater management has to be linked with more field research and scientific knowledge on changing pattern of water use from different sources, demand control, dynamics of pollutants in the groundwater flow, aquifer's attenuation capacity for contaminants under natural and exploited conditions. Such evaluation at regular intervals may be useful in delineating groundwater protection zones around major catchment areas. Groundwater vulnerability to pollution and depletion can be partly minimized or controlled by short-term and long-term management goals restricting migration of population from surrounding states, unplanned groundwater abstraction, unplanned agro-chemicals application in the potential groundwater recharge zones, and eliminating wastes disposal within these protection zones, through strict enforcement of regulatory measures.

Actions Desirable

General

1. Cover the interdependent and inseparable aspects of quality and quantity in all matters of global water assessment, monitoring and management.
2. Strengthen simple systems and protocols for measuring, monitoring, analyzing, summarizing and disseminating water quality information.
3. Bridge the gaps in understanding the links between freshwater microbiology and hydrological processes and water quality.

4. Learn from past successes and failures and adjust policies to local conditions for monitoring, water quality criteria, land use and pollution reduction.
5. Capacity building at the public, professional and institutional levels.
6. Deal the links of water quality and human health with in an interdisciplinary and inter-institutional manner.
7. Strict enforcement of water quality laws, wherever they exist.
8. Public awareness and public participation for policies and actions for water quality management and environmental protection.
9. Develop indicators of the status, trend, availability and demand of water resources, to provide user-friendly and comprehensible information to non-specialists.
10. Studies on intense competition among water users (private and public).
11. Studies on intersectoral competition between irrigated agriculture and urban water supplies.
12. Studies on competition between communities located at recharge and discharge areas of aquifer systems.
13. Studies on competition over transboundary aquifers (exploitation and pollution).

Data and Improvement of Water Resources Assessment

1. Self-education of water specialists about the needs of the people; with more effective ways of making their information available and useful.
2. Take into account all relevant components of the hydrological system and interdependencies among those components.
3. Consider surface and groundwaters as two complementary components.

4. In addition to measurements of precipitation, streamflow and groundwater level; provide information on glacier dynamics, soil moisture, geological characteristics of aquifers, contaminants, flora and fauna present in water bodies.
5. Continue efforts directed towards understanding the physical and biological processes that control how hydrological systems function.
6. Establish formal quality assurance procedures for observational data and model implementation, adoption of appropriate common standards and documentation.
7. Fully utilize the potentials of isotopes techniques, modern computing, remote sensing and information management technologies.
8. Resolve the issue of intellectual property rights to water information.

Impact of Human Activity on Water Resources

1. Harmonize computing methods in defining water uses and water needs. Evaluate time and spatial scales, especially in terms of groundwater-related issues.
2. Strengthen regulations and implementation of water laws through institutional reform and capacity building.
3. Develop effective policies for water protection, especially of groundwater.
4. Capacity building at all levels, with introduction of new multidisciplinary approaches in all the sciences, including social sciences.

Extremes of Water Resources and their Management

1. Divide the time horizon of potential problems into three time frames: (i) short term (days to weeks): floods, weather-related events, accidents, etc.; (ii) medium term (months to years): droughts, social disruptions, migration,

water quality, environmental degradation including effects of human activities, economic factors etc. (iii) long term (years to decades): climate change, population growth, etc.

2. Better assessment of water resources availability using probabilistic approaches.
3. Education and increased awareness are paramount prerequisites.
4. Promote appropriate and efficient water use and re-use in agriculture and industry.
5. Actively promote water demand management in water scarce areas.

Economic and Social Aspects of Water Resources

1. Further studies to gain a better understanding of the value of water in its different uses (e.g. agriculture) and the scale of water infrastructure for water pricing and water transfers, to improve allocation of limited water resources between competing users.
2. Develop improved multidisciplinary approach for impact assessment of land use and climate change on water resources.
3. Conduct studies on the cultural aspects of water, consumer behaviour, and the willingness to pay for water and water services.

Strategies for Mitigation of Demand Gap

Irrigation sector

- Participatory approach in Irrigation Management; Reducing Conveyance losses.
- Operation and maintenance of Irrigation Systems.
- Rationalization of Water Rates; Equitable Water Distribution.

- On-farm Management; Conjunctive Use of Surface and Groundwater.
- Integrated use of poor quality and good quality groundwater.

Domestic sector

- Water Conservation measures; Artificial Recharge of Ground water.
- Rainwater Harvesting; Public Awareness and participation.
- Appropriate Pricing; Recycle and Reuse of water.
- Use of treated effluents in place of filtered water for Horticulture and Gardening.

Industrial sector

- Setting up norms for water budgeting.
- Modernisation of industrial process to reduce water requirement.
- Recycling water for cooling purposes.
- Rational pricing of industrial water to compel adoption of water saving technologies.
- Proper treatment of effluents and use of treated water by industrial units.

Resource characteristics and distribution differ from region to region and are geographically bound entities, characterised by specificity of occurrence. Therefore, each area/region should be treated separately. Whichever approach is adopted, for effective implementation of management decisions at local and regional level, comprehensive, reliable and timely information on dynamic natural resources is very desirable. The development and management of these resources must be based on an adequate knowledge of a clear

aggregate status/situation of water resources system and its renewability. Further systematic monitoring network and research is needed to recognize these inextricable linkages and the hydrological and geomorphological processes, especially aggressive to depletion and degradation of water. Crop or cropping sequences with lesser evapo-transpiration and improved method of irrigation and agronomic practices should be preferred in areas affected by falling water table and contamination. There is need for: (a) the development of an advanced technological 'package', suitable for long-term needs of the users, planned in association with the users; and (b) programmes of training in appropriate newer technologies having more knowledge intensive mandate.

Most of the times, in the absence of adequate data it is difficult to estimate key parameters by any one advanced technology alone. It is important to conduct further research to identify techniques for the rapid and accurate evaluation of water-balance components. Fusion of different modern techniques such as remote sensing, aerial photography, satellite imagery, GIS, etc., with ground-truth data using isotopic, geophysical and physical techniques, and other information systems can provide detailed insight into many long-term processes governing water dynamics under changing landuse, and could be helpful in identifying water protection zones and assess fresh water potential. There is a need for reorientation and consolidation of efforts from the existing compartmentalized disciplinary mode based research to problem-solving inter-disciplinary eco-regional approaches, realizing the significance of close inter-linkages with physical sciences, earth and atmospheric sciences, water resources, environment, etc.